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HANDBOOK
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MECHANICAL AND ELECTRICAL
COST DATA

Giving Shipping Weights, Capacities, Outputs, and Net Prices of Machines and Apparatus, and Detailed Costs of Installation, Maintenance, Depreciation and Operation, Together with Many Principles and Data Relating to Engineering Economics

BY

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PREFACE

Our principal reason for thinking that these notes would be useful to others, is that we have found them indispensable within our own practice and not available in other form. Although the civil engineering field has long been provided with two cost handbooks, no similar book in the mechanical and electrical field has been obtainable.

The main purpose of this book is to place under the hand of the engineer in the most convenient form for reference the largest practicable amount of information bearing upon economic and intensive construction production and transportation in the mechanical and electrical fields. So far as possible, the material has been classified along the lines of the work that one man is likely to be called upon to do at the same time, and this arrangement has been supplemented by a very careful and thorough index, which should be freely used in order to get the maximum benefit from the book. We have borne in mind particularly the practical requirements of

The Designer,
The Appraiser,
The Chief of Construction,
The Superintendent of Operation,
The Engineering Student.

This Handbook of Mechanical and Electrical Cost Data is designed to be a companion volume to our two civil engineering books, the Handbook of Cost Data by Gillette, and the Handbook of Construction Plant and Its Cost by Dana. In method of treatment it resembles both of these, but its field, as the title indicates, is mechanical and electrical. These three handbooks are so written as not to overlap, and can be used to supplement one another. This has enabled the authors to devote almost the entire 1716 pages of this volume to purely electrical and mechanical subjects. Thus, there is very little in this book on excavation, concrete, structural steel work, water pipe and other work classed under civil engineering and treated in Gillette's Handbook of Cost Data. Nor does this volume contain many cost data relative to derricks, concrete mixers, motor trucks, rock crushers, etc., which are treated in Dana's Handbook of Construction Plant and Its Cost.

For more than twenty years we have specialized in cost data, and during that time have conducted detail appraisals aggregating $650,000,000 and embracing every class of plant treated in our handbooks. It is not to be inferred that the authors claim to have personal knowledge of every detail covered by their valuation work, but their staff of engineering assistants has been so organized as to supply all the detail knowledge required for appraisals of every character; and to this staff was intrusted much of the work involved in the preparation of this work.

Rewriting a book on cost data is often regarded as being neces-

sary every time that the levels of wages and prices change substantially. If this were true, a cost book would scarcely be off the press before rewriting would be necessary, for the prices of some things change every month. The authors have gone to considerable pains in the Introduction, Chapter I, to show how cost data are usable even where wages and prices have changed since the compilation of the cost data. Those who are inclined to criticise any given cost on the score that it is "not up to date" are requested to read the first part of this Introduction with care.

Where the methods used are the same methods in use today, the age of cost data has nothing to do with their value provided the original rates of wages, etc., are given. Applying the present rates of wages will then make the cost data absolutely up to date. Why this has not been more thoroughly recognized by critics of cost data we do not know, but it seems to be the fact and we must guard against it as much as we can by this warning.

Several professors of engineering have expressed the intention of having their students use this book in making estimates of cost, and for this purpose it has been suggested that all our data should have been reduced to some "standard wage" and "standard price" basis. Admirable as such a standardization might be, it is one of those things that the student fails to find anywhere. Instead of helping him by standardizing the data for him, we conceive that we should be hindering his progress; for one of his functions as a practicing engineer will be the interpretation of published cost data that conform to no standard whatsoever.

One of the greatest difficulties that we have to contend with in the use, as well as the presentation of cost data, is found in the fact that they come to us, whether originally or at second hand, in various kinds of forms. A cost statement on one job will include overhead charges, superintendence, interest, depreciation, etc., and the final unit costs will represent perhaps very nearly the total unit cost to be reckoned with in an estimate. Another statement from perhaps a neighboring job, possibly collected by the same man in the field, will give costs which do not include overhead charges, interest or depreciation. In making use of such data it is naturally essential for the reader to appreciate not only what is included but what is omitted, and not allow himself to be misled by the incompleteness of the statement at hand. Published costs are frequently incomplete, yet very useful in spite of incompleteness. For example, "overhead costs" may not be stated although all the "direct costs" are given; or, again, operating expenses may not include repair and depreciation costs. Nevertheless, a skilled estimator can use such incomplete costs to advantage, for he can himself estimate the missing elements. To facilitate supplying such omissions and to aid in correcting underestimates of "overhead costs" and "upkeep costs," we have given a good many data in Chapter I, accompanied by a somewhat detailed discussion of these important elements of cost.

In general, our plan has been to give capacities, weights and average normal net prices (f. o. b. factory) of machines and equipment of different types and sizes, together with labor and other costs of installation. Detail operating expenses, inclusive of repairs and renewals, are given for many plants; and, wherever possible, these costs have been accompanied by concise descriptions of the plant and its first cost. We have selected for this purpose prices and expenses that existed prior to the world war; and in most cases the data are presented in such a way that relatively little

work will be involved in applying them to existing conditions in any part of America, by following the methods outlined in Chapter I.

No book on cost data is any more fool proof than any other technical publication. It requires as much judgment to use costs intelligently as to use tables of safe stresses in engineering design. To the man of judgment and experience it is believed that the information contained in this book will prove to be indispensable, as we have found it so in our own office. To the technical student of limited experience it should offer an introduction to the economics of engineering.

In the compilation of data we have drawn largely from those collected by us in the course of our appraisal and rate case work. Valuable unit costs have also been placed at our disposal by Messrs. Henry L. Gray, Arthur R. Kelley and F. S. Burroughs, valuation engineers.

We believe that the greatest courtesy we can offer to the writer of a technical masterpiece is to place his material in permanent form where it can be most readily utilized, and we have therefore made the freest use of the data obtainable from all sources. In doing so we have made it a rule to give credit to its original source throughout the text and we wish to express our obligation and that of the entire engineering community to those men who have contributed by their labors and out of their ripe experience to the periodical literature of our profession. We wish also in particular to acknowledge our indebtedness to those members of our engineering staff and that of the Construction Service Company who have so ably assisted in compiling the data and reading proofs: Messrs. Allan C. Haskell, James M. Kingsley, John C. Black, Arthur P. Ackerman, Charles R. Thomas, Jr., and Walter L. Anderson.

THE AUTHORS.

New York, July 1, 1918.

CONTENTS

MECHANICAL AND ELECTRICAL COST DATA

CHAPTER I

GENERAL ECONOMIC PRINCIPLES

Engineering is the application of science to the problems of economic production. The engineer's ultimate aim, therefore, is to effect a desired result at a minimum cost. To this end, where it is feasible, the engineer should formulate a unit cost equation in which all the dependent variables and constants are included, and he should then solve for a minimum unit cost. But whether he is able to employ this ideal method or must use cruder methods, he must eventually express all the items in terms of money or its equivalent.

Put differently, every economic problem resolves itself into the determination of quantities to which unit costs are applied. No economic problem can be solved merely by the use of qualitative terms; yet many a poor reasoner attempts to solve the most complex of economic problems without the use of a single item to which a definite cost is assignable. Volubility is vainly made to serve instead of valuation.

Imperfect Cost Data. The term data is coming more and more to designate statistical facts rather than qualitative facts. Cost data are obviously essential in solving economic problems. Yet there still exists a prejudice against published cost data. If, however, each engineer were to rely solely on cost data gathered by meager pickings from his own little crab-apple tree of experience, economic progress would be decidedly restricted. Accordingly each year witnesses more complete and detailed publication of costs in most lines of engineering work. It is true that many of the cost data are incomplete, or insufficiently explained, and therefore apt to be misleading. It is also true that men entirely inexperienced in the use of cost data may misinterpret even the most complete data. But neither the deficiences in published data nor defective reasoning in their application should serve as an argument for restricting the publication of such information. In spite of the risk of misuse, "a half-loaf is better than none." Moreover a half-loaf of knowledge on a given subject is almost universally the precursor of a full loaf.

Published cost data are usually defective, but defectiveness is characteristic of nearly all economic data whatsoever. Who, for

example, can accurately forecast the natural life of any generator, or any pump of given size and type under any specified service? Although we still remain ignorant of many economic facts, we shall scarcely become wiser if we fail to make use of such data as we do possess on the ground that the data are imperfect. Let us have done with fatuous criticism of published cost data, and bend our efforts to the gathering and publishing of more complete costs of all kinds under varying conditions.

How to Use Cost Data. If a unit cost has been so analyzed as to show the quantities of each kind of labor and of each kind of material involved in the production of the given unit, such a unit cost may be quite as serviceable a generation or more after its publication as it was when first published. Thus, the yardage costs of excavating earth with drag-scrapers and horses which Elwood Morris published in 1841 are applicable now, three-quarters of a century later; for we still use drag-scrapers for earth excavation, and we have merely to substitute present team and man wages for those used in the time of Morris. Curiously enough many men, even engineers, have failed to see that "out of date" cost data can often be thus brought up to date.

Rates of wages are frequently omitted in giving unit costs, but, if the date when the cost was incurred is given, it is usually possible to ascertain the wage rates that then prevailed. An experienced engineer often knows offhand the prevailing rates of wages that were paid in any part of the country at any given time. While it is true that wages of individual workmen often differ quite widely even in the same locality and at the same time, it should be remembered that this difference is usually consequent upon their individual differences in efficiency. Thus, when railway carpenters were paid $2.50 a day and contractors' carpenters were paid $3.00 in the same locality for the same class of work, the carpenters working for a contractor did fully 20% more work daily. Hence the unit cost of carpenter work did not differ materially even where the wage differed 20%.

The labor cost of installing a machine is very often estimated as a percentage of the cost of the machine. Suppose, for example, a given machine was installed 20 years ago at a labor cost that was 10% of the cost of the machine. If the general level of wages and machine prices has risen 75% since that time, then the ratio of labor cost of installation to machine cost would still remain 10%; and the labor cost data of 20 years ago would remain applicable today if applied as a percentage to the present cost of the given machine.

The labor cost of installing equipment is frequently estimated in dollars per ton of weight. Although the weight of a machine of given size and type is seldom given in an article containing costs of machinery installation, the weight is usually ascertainable from tables such as are given in this book; and then a published labor cost of installation of a machine may be converted into a cost per ton. Old installation costs per ton may be brought up to date by making proper allowance for the rise in wages.

In making tables that give the prices of machines and equipment of different types and sizes we have given also the weights. It is therefore possible to deduce from our tables the price per lb. of each size and type of plant-unit. Our prices were normal prices at the factories in 1913 and 1914, prior to the world war. It might seem at first sight that these tabular prices will be valueless at least until the war is ended and normal economic conditions are restored. Yet a little consideration of the matter will show that our tables of equipment prices may be used effectively now. To illustrate, suppose it is desired to estimate the present price of electric transformers of different sizes. Secure either the price actually paid recently for a given transformer, or secure a quotation, then divide this price by the price given in our table, and thus establish the factor by which to multiply other prices in the same table to get present prices. This procedure will save time and trouble. Moreover, it will be found much easier to secure a few quotations from manufacturers or their agents than to secure as many as may be needed for an approximate appraisal or a preliminary estimate of cost of a proposed plant unit.

In this connection it should be noted that manufacturers usually quote higher prices when they think the prices are to be used for preliminary estimating or for appraising than when they regard their prices as actual bids upon equipment to be furnished. As our price tables are based on bids or on plant actually purchased, it is evident that these tables will have value for many years to come, if intelligently used as suggested.

In estimating costs there is always danger of omitting items, either through ignorance or carelessness. If the cost data in this book served no other purpose than to prevent such omissions, the publication of the book would be justified. Danger of omission of cost elements is particularly acute when the estimator is dealing with a class of work with which he is not thoroughly conversant.

Estimates of the cost of plant are usually preliminary to an estimate of the unit cost of the product or service of the plant. When this is the case it is important to realize that probable errors in estimating the per cent. of "fixed charges" and the "load factor" are apt to outweigh probable errors in estimating the cost of the plant. Thus the "fixed charges" (interest, depreciation and taxes) may be estimated by A at 10%, whereas B may estimate the same at 15%. If A were to estimate the first cost of the plant at $150,000, B could estimate it as low as $100,000, and the two estimators would arrive at the same annual cost of fixed charges.

Comparatively few engineers seem to realize the relatively great importance of accuracy in estimating the percentages allowed for "fixed charges," yet the same engineers will split hairs over estimates on the first cost of a plant. This fact is repeatedly made evident in rate cases before public utility commissions where acrimonious debates of considerable length often occur as to the "value" of plants, only to be followed by the most cursory discussion of depreciation annuities and "rates of fair return" on the investment. It is exceedingly important to bear in mind this rule:

Each per cent. of difference between two estimates of fixed charges divided by the total percentage allowed for fixed charges in the lower estimate, gives the percentage of increment in plant investment that is at stake. Thus if two estimators agree on a plant value but one estimator, A, allows 10% for fixed charges, whereas the other estimator, B, allows 14%, dividing the difference of 4% by 10% gives 40%, which is the percentage by which A would have to increase the plant value to get annual fixed charges equal to those of estimator B.

When estimates of plant are thus viewed in the light of subsequent calculations of "fixed charges," there is apt to result far greater study of the questions of depreciation, interest and tax rates, to say nothing of insurance and even repair rates which are also commonly applied as percentages of the plant investment. Moreover, it is also perceived that great precision in estimating the cost of a plant, even were it attainable, is a useless refinement where equal precision in estimating "fixed charges" is not attainable.

By a parity of reasoning it will be seen that unless the load factor, or ratio of actual output to capacity output, of a plant can be estimated with great accuracy, it is fruitless to estimate the cost of the plant with great accuracy. Here, again, engineers have been inclined to give relatively scant consideration to average output factors while splitting hairs over estimates of plant cost. What avails it, for example, to estimate the probable cost of a factory with considerable precision, if there is to be nothing but a crude guess as to the average "load factor" or annual output of the factory?

Engineers have often excused themselves for not estimating carefully such things as "fixed charges" and output factors, on the ground that these were matters for the owners or managers of the plants to decide. But the day when such an excuse will be acceptable is gone. Even a designing engineer is now presumed to study and apply all the economic factors, for if he does not he can not design the most economic plant for the given purpose.

Unfortunately depreciation data and output factors (or load factor data) are not as abundant as could be desired. They are cost factors of great importance, and their usefulness is little impaired by age. We have made a beginning in recording miscellaneous data of this character in this book, but we are well aware that it is only a beginning.

Definitions of Economic Terms. Few economic terms are used in the same sense by all authorities. There have not been many attempts to standardize economic nomenclature, and it is not likely that standard terms will be generally adopted for many years to come. This makes it important that the student of economics shall early form the habit of carefully defining the terms that he himself uses, and critically examining the definitions that others use.

Many writers do not define the economic terms that they employ, apparently taking it for granted that any dictionary will

elucidate their meaning. Not infrequently such writers themselves have a rather hazy conception of the scope of the several economic words.

The definitions that follow in this chapter are those that the authors have adopted or have formulated for their own purposes. They conform fairly well with "general usage," but are not in every instance in general use.

Economy is the judicious expenditure of labor, materials and energy in the attainment of a required end.

Economics is the science of the general principles applicable in securing maximum economy.

Economic Efficiency is the ratio of actual performance to an ideal or standard performance. The single word efficiency is often used, instead of economic efficiency, in this sense.

Engineering is the application of science to the problems of economic production

Engineering Economics is that part of economics most commonly applied in the practice of engineering

Industrial Economics is that part of economics most commonly applied in financing, organizing, purchasing, producing and selling.

Political Economics is that part of economics most commonly applied in political or social management.

General Discussion of Economics. The word economics is derived from a Greek word meaning household management. Political economists have attempted to restrict its use to their own particular branch of economics; but this limitation of the word is not approved by those interested in other branches of economics. Engineers in particular refuse to use the term economics solely in reference to the science of political management.

Economics is often defined as being "the science that deals with the production and distribution of wealth," or more briefly as "the science of wealth." But such definitions seem to be too broad. Engineering also deals with the production and distribution of wealth. It seems better to define economics in such manner as to make clear the fact that it deals solely with *principles* of general application in securing economy The manufacturer, the merchant, the engineer and the politician may all apply the general principles of securing economy, and to this end they should study economics. But each in his own sphere should possess not only a knowledge of certain principles applicable in securing economy of performance, but should have acquaintance with many facts and details not classifiable as parts of the general science of economics.

To a merchant the "required end" is a maximum annual profit with the aid of the capital that he commands. Hence for him a maximum annual profit is the "maximum economy."

To an engineer the "required end" is usually a minimum unit cost, which is the "maximum economy" that he seeks

By every class of designer or manager of productive plants a maximum of economy is the desideratum in the attainment of which the science of economics is immeasurably valuable.

Mr. Frank A. Vanderlip, president of the National City Bank

of New York, said at a recent convention of a school of finance for business executives: "I believe we are a nation of economic illiterates. There is a science of business. It is something teachable." Yet a few years ago when engineers began to say that there is a science of management and that it is teachable, the scoffers almost drowned the announcement with laughter "Science, indeed!" they exclaimed "You can't teach management. Managers are born, not made." Now it is admitted that managers are first born and then made.

Value is exchangeable worth, usually expressed in money.

Price is the quantity of money exchanged for property or service.

Cost is the money outlay and debits incurred in securing property or service. The price charged by a seller is always part of, and may be all of, the cost to the buyer. "Debits incurred" will be explained later.

Profit is the excess of the price secured over the cost incurred by the seller.

Unit Price is the price per unit of property or of service; e. g. $20 per ton, or 10 cts. per kilowatt-hour.

Unit Cost is the cost per unit of property or of service

Unit Wage is the wage per unit of employee's time; e. g. 30 cts. per hour.

General Discussion of Value, Price, Cost and Profit. Economics might roughly be defined as the science of value, price, cost and profit, so important and far reaching are these four words. One of the commonest errors is to suppose that the full import of these words is attainable by reading of short definitions such as those above given.

Value is exchangeable worth, it is true, but this tells nothing as to how the value of a waterfall, or a mine, or a factory site, or a patent, or the "good will" of a business is ascertainable.

Cost is money outlay and debits incurred, but this tells nothing about what the true debits are.

Profit is excess of selling price over cost, but since true profit depends on what constitutes true cost, not much is explained by the definition of profit until there is a very thorough understanding of what constitutes a true and complete cost.

Scores of thousands of men are both deceived and self-deceived every year as to values, cost and profits, because they have never studied economics. The majority of industrial failures is attributed to lack of knowledge of cost keeping and cost estimating, but this, important as it is, is only one phase of the broad subject of economics.

Cost has two meanings, one quite elementary and the other more complex. In its elementary sense, the cost of a thing to a given owner is the sum of the prices, or total price, paid or payable by that owner at the time the thing was acquired. This may be called elementary cost.

a given time is the sum of all net debits chargeable to the thing up to the given time, including the value of the owner's time.

This cost might be called economic cost, in order to distinguish it from elementary cost.

Elementary cost differs from economic cost in that it does not include sacrifice costs.

Sacrifice cost is any payment (such as interest, supervisory wages, depreciation annuity and risk insurance) foregone during the period that a business is being developed or built up to a point where it earns a normal return on the investment. Sacrifice cost may therefore include interest during construction as well as its sequel, development cost or accumulated deficit in fair return on the investment.

The following are five broad definitions of cost terms:

Cost of production includes money outlays, debits incurred, proprietary losses of normal income and compensation for risks involved in production.

Cost may be divided into two classes of business debits:

1. Debits of the business to others than the proprietor.
2. Debits of the business to the proprietor.

In well kept ledgers all of the first-named class of costs will be found, either as property costs or as operating expenses, but it frequently happens that not all — and sometimes not any — of the second class of costs are entered in the ledgers.

Costs of production may be divided into two parts:

1. Direct costs.
2. Indirect costs.

Direct Costs are those costs directly assignable to a group of similar units of product without prorating.

Joint or Indirect Costs are costs that cannot be directly assigned to a group of similar units, but must be prorated among different groups of units.

Unit Cost is the cost per unit of product, and is determined by dividing the total cost assigned to a group of units of product by the total number of units.

A unit cost includes all the direct costs and it may include all or nearly all the indirect costs, depending upon the method of accounting or cost analysis.

In appraisal work, as well as in estimating the cost of projected work, it is customary for engineers to use unit costs that include only part of the indirect cost, the remainder of the indirect cost being called "overhead cost."

Overhead Cost is that part of the indirect cost not included in the unit costs.

No hard and fast line can be drawn between unit cost and overhead cost. It is entirely a matter of more or less arbitrary definition. If a company does its construction work by contract, the contractor's *unit prices* are the company's *unit costs;* but the contractor's unit prices include all of his overhead costs. Hence, if a company does its construction with its own forces, its overhead costs will ordinarily be greater than if it does its work by contract, due to the differences in accounting.

Several recent decisions of public utility commissions serve to call attention to a rather general lack of knowledge about over-

head costs. One decision even goes so far as to impute dishonest motives to certain engineers who had estimated overhead costs at what appeared to be a very high percentage. Dishonesty is rarely to be found in appraisals of "overheads," but ignorance is certainly more in evidence. At times this ignorance results in excessive allowances for overhead costs, but quite as often it leads to under-estimates. Why, it may be asked, are engineers ever ignorant in such matters? An answer will be given to this question first, and then to several other related questions that often bother commissioners as well as company managers.

To begin with, the term overhead costs, or its equivalent, has no generally accepted meaning. In its broadest sense any cost is an overhead cost if it cannot be directly assigned to a given class of construction units, and in this sense overhead cost is identical with "indirect cost." A better conception of the difficulty of defining overhead cost, except in a general manner, will be evident upon defining "cost" and "unit cost."

The impression prevails that all the actual costs of a plant are to be found in the plant account of a well kept set of ledgers. The fact is that some cost items rarely appear in the plant account at all, notably interest during construction. And again, operating expenses are often charged with plant or capital costs, notably managerial costs.

Appraisal engineers usually, although by no means universally, limit the items of construction "overhead costs" to the following:

1. Engineering and Inspection.
2. Supervision (other than gang foremen and the profits of contractors).
3. Organization (preliminary to construction).
4. Administration, Accounting and Clerical.
5. Legal.
6. Insurance (casualty, fire and title) and Damages.
7. Taxes.
8. Interest.
9. Contingencies, Omissions, Waste and Incidentals.
10. Broker's Fees.
11. Promoter's Profit.

Broker's Fee and Promoter's Profit are not infrequently omitted by appraisal engineers, but the remaining nine items usually appear, either separately listed or grouped together. They are commonly expressed as percentages, either of all the direct charges taken as a whole or of some of the direct charges, or of the direct charges plus some of the overhead charges. This variation in practice is itself confusing, but when we add to it variations caused by the "burying" of some of these eleven "overheads" in the unit prices, the confusion often is so great as to lead to complete misapprehension on the part of those not accustomed to cost analysis. Indeed even skilled estimators are frequently found to be using "overhead percentages" erroneously.

It will be observed that we have omitted "Going Value" or "Development Cost" from the list of "overheads," and in doing so

we follow present practice, although "Development Cost" is itself largely interest during construction and its sequel — deficit in interest during the development period.

We are informed by C. M. Larson, chief engineer of the Wisconsin Railroad Commission, that his estimated "overhead costs" *exclude* items 6, 10 and 11 of the above list. Item 6, Insurance, is included in the unit prices that he uses. Item 10, Broker's Fee, is taken into consideration by the Wisconsin Commission (as we interpret their decisions) in arriving at the proper rate of "fair return" on the investment, since brokerage fees commonly constitute part of the discount on bonds. Item 11, Promoter's Profit, appears not to receive recognition by the Wisconsin Commission. Mr. Larson informs us that he usually adds to the direct costs 15% for overhead costs on "the larger properties which show a high type of construction," and he intimates that, of this 15% very little constitutes Item 10, or Contingencies, because his "inventories are usually made quite complete by means of co-operation of the officers and agents of the companies." For small plants Mr. Larson commonly allows 12% for overheads. These percentages — 12 and 15 — seem very low, and we believe they are low where a utility company does most of the construction with its own forces. Mr. Larson, however, uses unit prices that are assumed to be fair *contract prices* for the plant "in place," which puts a somewhat different light on these low overhead percentages.

As to unit prices he says: "These prices cover contractors' profits, liability insurance, and, in a word, every item which is ordinarily included in the same to a general contractor." Since a general contractor is a business manager, and since his subcontractors are really superintendents, it follows that, when their services are paid for in the form of profits included in their unit prices, Items 2 and 4, Supervision and Administration, are smaller than where a company does the construction with its own forces. This alone explains a considerable part of the difference between percentages estimated by different appraisers for overheads. Even the same appraiser may use different overhead percentags at different times, if for no other reason than to enable him to have an appraisal that can be readily compared with the accounting records. Thus, in Gillette's appraisal of the steam railways of Washington State, he included the general contractor's 5% profit in the unit price, by adding 5% to the subcontractor's price. Thus a large part of Item 2, Supervision, was automatically "buried" in the unit price, which was in accord with steam railway accounting practice. But in our appraisals of electric railways, electric power and light properties, and telephone plants, knowing that many companies do most of their construction with their own forces, we have used unit prices that often included relatively little or no Supervision (other than gang foremanship). Even in these cases it occasionally happens that a manufacturing company undertakes to do much of the engineering and supervision involved in laying out and installing apparatus, and then a large part of such "overheads" as engineering and supervision are automatically buried in the prices charged for apparatus installed "in place."

In the appraisal of land and right of way it often happens that the appraisal engineer has no voice as to "overheads." Then all "overheads" may be lumped in with the price fixed upon the land by real estate experts. This was what was done in the original appraisal of the steam railways of Washington, and it has led not a few writers to misapprehension as to the overhead percentages used in that appraisal.

In Item 2, Supervision, we find that some utility companies include "dead time," traveling expense, unapportioned freight and carriage, and the like, under this head. To put the "dead time" (due to bad weather and holidays) of laborers in this account is a mistake, it seems to us. Similarly, traveling expense of laborers and unapportioned freight should not be called Supervision. Nevertheless they are sometimes charged to such an account. Even tool expense may be occasionally found there also.

Perhaps we have gone far enough in this discussion of details to indicate the danger that lurks in ordinary comparisons of "overhead percentages," particularly when the accounting practice of different companies is not thoroughly understood. But one more instance — a very striking instance — should be given to emphasize this point. Most large companies build additions to plant at the same time that they make repairs and renewals. Often the same gangs make both renewals and additions simultaneously. The same engineering, managerial, and executive forces are usually engaged in maintenance as well as on new construction. Therefore, it becomes necessary to prorate engineering, supervision, etc., to two or more distinct classes of work. Such prorating may be done according to different theories, the two most common being: (1) In proportion to the cost of direct labor, and (2) in proportion to the combined cost of labor and materials. These two methods rarely give the same results; often the results are widely different. Maintenance work generally involves a relatively high proportion of labor to material costs, whereas the converse is often true of new construction. Hence a company whose practice is to allocate engineering and supervision between maintenance and new construction in proportion to the direct labor involved will have a plant account containing lower overhead costs than a company whose practice is to allocate these overheads in proportion to combined costs of material and labor. Evidently the theory of such prorating has an important bearing upon final results. As an illustration we may cite one company whose new construction annually amounts to many millions of dollars and whose maintenance costs are equally large. Upon analysis of that company's costs, we found that its overhead charges on new construction would have been 3% greater than they appeared in the plant account had they been apportioned according to total costs instead of according to direct labor costs.

Some companies charge all general management, auditing, legal expense, etc., to operating expense, and thus reduce the overhead plant chargs.

It may be said that overhead percentages should be determined

solely by analysis of construction costs of companies during construction periods and prior to beginning operation. But to confine analysis to such companies would eliminate most of the new construction of public utility companies throughout America.

Often it is said that it matters not in the end whether overhead charges are improperly prorated or not, for by as much as the capital account is undercharged, by that much will operating expenses be overcharged. The users of this argument lose sight of the fact that an appraisal usually marks the passing from the old régime of *laissez faire* to the new régime of state regulation. One of the objects of such an appraisal then is to start the new plant account as nearly right as practicable.

True plant cost is independent of accounting methods, of whether property has been paid for or out of earnings or by the sale of securities. But accounting records can be used as evidence, from which true plant cost may be inferred, and to that end it is desirable that both the property accounts and the maintenance accounts be carefully analyzed at least for a number of years back. Upon such analysis adjustments can be made. Then correct unit costs and correct overhead costs can be derived. To this use of accounting records many engineers do not resort; their failure thus to use accounting records explains most of the ignorance respecting overhead costs, and makes clear why engineers have so frequently underestimated "overheads"

In this connection it may be remarked that while most engineers are fairly familiar with contract prices, and while some engineers are equally familiar with actual unit costs, relatively few engineers know from personal study of accounts what overhead costs average under given conditions. Until quite recently the accounting records of few utility companies were open to the study of engineers. And even when the records were available not many engineers analyzed them thoroughly, both as to operating and construction charges. The consequence has been that engineers employed by public service commissions have commonly underestimated overhead costs. Engineers employed by companies have ordinarily been closer to the mark, but occasionally have grossly overestimated overhead costs because they were guessing.

In a recent commission decision, the overhead costs estimated by a commission's engineers were rejected as being too high, although, in fact, they were much too low, in our judgment. The commission reasoned that because the plant account of the company showed nominal charges for engineering and supervision, and no charges for interest during construction, it could not be possible that the company had spent much for these items. This is an instance of a sort of blind faith in "book values," a faith, by the way, that would quickly have ebbed had the company been found to have "book values" that greatly *exceeded* the commission's engineer's estimate of reproduction cost.

Interest. Very few operating companies charge any *"interest during construction"* when new construction proceeds *pari passu* with renewals. In other words, after the original nucleus of a

plant is built, the "interest during construction" account, if ever there was one, is closed. In the case of railways, the interest account contains only interest on bonds and notes. Hence it usually does not adequately represent full interest on all the plant even during the original construction period. In our early appraisals we did not recognize this fact and accordingly underestimated "interest during construction."

On the other hand there is often a slight duplication of interest charges arising from the practice of making a per diem charge for "train service" which is itself high enough to cover interest on the rolling stock. Analogous to this is the practice of charging for transporting their own freight over their own lines at rates that are high enough to cover part, if not all, the interest on the track and equipment.

Interest during construction, as we now view it, should be charged at the full "fair return rate" rather than at the bond interest rate. Otherwise the investor fails to get a "fair return" on his money during the construction period.

Brokerage. It has often been claimed that *bond discount* is a proper "overhead charge," but usually this claim has been rejected by commissions. Commissions have reasoned that bond discount merely reflects the rate paid for the use of money, and is, therefore, to be considered only as a factor in determining the "rate of fair return" on the investment. This reasoning, however, is not wholly correct. Bond discount is a composite of two entirely distinct things: (1) Brokerage fee and (2) advance payment to the bond purchaser. The broker requires part of the discount to compensate him for investigating the property, giving it the endorsement of his approval, circularizing his clientele, advertising and selling the bonds. First, in the case of a large issue, there is the wholesale broker, and, second, there are many smaller firms, who retail the bonds that they have bought from the wholesaler. Securities are thus sold as if they were merchandise. It costs money to market them. The brokerage fee, therefore, is just as much a part of the cost of the property as is the engineering. Indeed, there is often not a little engineering involved in the study of a property by the representatives of investment brokers.

Occasionally a witness who has testified as to brokerage fees is asked such a question as this: "If Jones builds a $10,000 house with his own money, whereas his next door neighbor, Smith, builds a $10,000 house with borrowed money, is Smith's house worth more than Jones'?"

The answer is no, and upon receiving such a reply it is presumed that the entire argument in favor of brokerage as an overhead cost is overthrown. But let the cross-examiner himself be asked. "If Jones, who is an architect, builds a house, and his neighbor, Smith, who is not an architect, but hires one, builds a duplicate house, is Smith's house worth more than Jones'?"

Here the negative answer might with equal reason be used to support the contention that architect's fees are not a proper overhead charge. The fallacy in this line of reasoning arises from

the confusion of *cost* with *value*. The "worth" of a thing is its value, which may be quite distinct from its cost. Appraisals of utility properties are *cost* of reproduction estimates whenever they consist of a summation of priced-out quantities. The commercial *value* of a utility property is the present worth of its prospective earnings, or its equated annual net earnings capitalized by dividing them by the rate of fair return. While neither interest during construction, nor taxes, nor brokerage fee, nor many another item adds to the commercial *value* of a property, it does add to its *cost*. Whatever normally increases cost is an element to be appraised by one who is seeking either true investment or true cost of reproduction.

Among court decisions on this point of brokerage fee, none is better expressed than the decision (Jan. 13, 1913) of the Royal Courts of Justice relating to the purchase of the National Telephone Co. by Great Britain. The Court said:

> Next, it is said that the cost of raising the capital necessary to construct the plant is not an item to be taken into account in finding the cost of its construction. . . . The company has given evidence, by way of example, that it cost them 4.41% to raise £5,500,000. No one has given evidence that it would not cost anything, nor has that proposition been put forward even in argument. I know of no commodity and no service that can be procured as of a right for nothing. I am clear that, as a fact, money cannot be procured for nothing. . . . It is not true to say that this involves the proposition that the value of plant varies with the credit of the constructor. The cost to be considered is the cost to the hypothetical constructor who is a person in good credit.

Accordingly the Court allowed a commission or brokerage fee of about 2% of the construction cost of a telephone plant having a total cost of about $65,000,000.

The brokerage fee on small properties is usually a higher percentage than on large properties, for reasons that are quite apparent.

Contingencies. Contingencies, as the term is ordinarily used by appraisal engineers, denotes the probable aggregate cost (or value) of items not formally listed in the appraisal inventory.

Contingencies may be divided into three classes:

1. Omissions of quantities through carelessness, ignorance or oversight.

2. Omissions of minor quantities, purposely left out of the formal inventory, either because of the difficulty of enumerating them or because of their relatively small value.

3. Underestimates of unit costs or values.

Some appraisers include an allowance for contingencies in their unit costs, in which case contingencies may not appear as a separate item, yet may in fact exist in the appraisal.

An allowance for contingencies is usually made by engineers in estimating the probable cost of *projected* work. Such an allowance is seldom less than 5% of the total of the schedule estimate, more commonly is 10%, and not infrequently reaches a much higher percentage, depending on the carefulness with which the plans

have been prepared, the degree of certainty as to the conditions that will be encountered, the experience of the engineer, and finally, the optimism of the engineer. A higher allowance for contingencies should ordinarily be used in estimating the probable cost of *future* works than in estimating the cost of replacing or reproducing *existing* works. It sometimes happens that the engineering records of quantities and the accounting records of costs are so complete and reliable that no allowance at all need be made for contingencies in an appraisal of existing works. This is particularly true when the works are comparatively new. However, as an engineer gains experience in estimating and particularly after he has had occasion to check over the appraisals of other engineers, whether in his own employment or as independents, he is more likely to recognize the necessity of some allowance for contingencies in nearly every instance. What this allowance shall be is a matter of judgment, but not necessarily a matter of mere guess-work.

Perhaps at the basis of the phenomenon of underestimating there is the psychological fact that most men are optimists. The hope that work can be done cheaply is father to the too low estimate. In addition to this well known cause there are many other reasons why estimates of cost tend to be too low. Some of these are not generally recognized even by expert appraisers. For example, in not a few articles, decisions and books on appraisals, there appear diagrams and tables of unit prices of materials — such as copper, steel, water pipe, etc.— accompanied by statements that the average of these prices over a period of years was used as the base price in the appraisal. This seems a philosophical method to use when *average* prices are sought, but closer investigation discloses the fact that it is not so philosophical as it seems, for sight is lost of the following basic fact in the business world where the law of supply and demand operates:

In general, average weighted prices are higher than average unweighted prices, because more materials are bought during periods of high prices than during periods of low prices — the higher prices being, in fact, the result of the greater demand.

This generalization is deducible from the law of supply and demand, but it may be arrived at inductively from the actual purchase records of large companies that have been in existence many years. As a corollary of this generalization, we can immediately infer that even the "average monthly" or "average yearly" prices of materials as published in the technical journals are often deceptively low, for they, too, are unweighted averages. The sale price of 1,000,000 lbs. of copper in the first week of a month is given as much weight as the sale price of 5,000,000 lbs. in the last week of the month, in arriving at the "average monthly" price.

The correct method of arriving at a true average, or weighted average price, is this: Multiply the number of units in each sale by the sale price, total these products and divide by the total number of units to get the weighted average price.

In this excess of weighted average price over unweighted aver-

age price, we have a good example of the sort of underestimating that justifies a contingency item in many appraisals.

Another common cause of underestimates by engineers is traceable to their lack of familiarity with the detailed records of the accounting department. The engineer may keep quite careful cost records in the field, yet fail to know some of the very important elements of cost that disclose themselves only in the records of the accounting department. This, perhaps, has been one of the greatest sources of underestimates in the past, but is fast becoming less in importance now that engineers are more frequently familiar with accounting practice and records.

In the following list of items will be found some of the things that not infrequently result in underestimates. Of course most of these items will ordinarily be provided for in the unit prices, but the fact remains that unit prices usually do not include sufficient provision for all items of cost. Hence the reason for an allowance for Contingencies and Omissions made up of such elements as the following:

ACCIDENTAL OMISSIONS OF QUANTITIES AND COST ITEMS

1. Quantities inventoried in the "field survey" but overlooked in the final summary.

2. Quantities seen but omitted because they were believed not to belong to the company.

3. Quantities not visible:
   - (a) Underground obstructions.
   - (b) Sewer connections.
   - (c) Foundations in quicksand, piling, etc.
   - (d) Rock excavation, hardpan, etc., beneath an earth surface.
   - (e) Clearing, grubbing and trimming.
   - (f) Pole butts treated.
   - (g) Ground braces, bog settings, concrete settings, etc., for poles.
   - (h) Work abandoned due to changes of plans after work was begun.

4. General cost items overlooked:
   - (a) Casualty insurance and contractor's indemnity.
   - (b) Fire insurance.
   - (c) Title insurance.
   - (d) Brokerage fee.
   - (e) Demurrage.
   - (f) Miscellaneous items.
   - (g) Value of leases.
   - (h) Taxes during construction.

5. Damage costs:
   - (a) Changing location of a highway, incident to building the utility plant.
   - (b) Ditto sewers, water pipes, etc.
   - (c) Ditto buildings.
   - (d) Ditto water courses.
   - (e) Severance damages.

ITEMS PROPERLY OMITTED IN THE INVENTORY TO BE COVERED BY A GENERAL PERCENTAGE ALLOWANCE (2 TO 5%)

1. Material wasted, stolen, etc.
2. Excess material needed for splicing, joining, trimming, etc.
3. Increased length of wire and cables, due to sags, dips, map shrinkage, inclines and slopes of ground.
4. Small items of hardware, miscellaneous small supplies, etc.
5. Disconnected installations and wiring, available for use.
6. Cost of reels and freight thereon.
7. Changes made after construction is begun, resulting in property lost, e. g., pole holes.

UNDERESTIMATES OF UNIT COSTS AND OVERHEAD COSTS

1. Use of average prices instead of weighted average prices.
2. Use of wholesale unit costs when, under no rational hypothesis, could work be done entirely wholesale.
3. Use of car-load freight rates throughout, when less than car-load rates would often be incurred.
4. Assumption of good weather conditions throughout, when bad weather, night work, etc., would normally occur for at least part of the work.
5. Assumption of continuous work, when delays due to non-shipment of materials and freight congestion on railways, would normally add to some unit costs. Other delays, such as those involved in securing right of way, also occur.
6. Assumption that surface conditions are sufficiently indicative of subsurface conditions, or that a few borings are ample to indicate subsurface conditions, resulting in underestimates of unit costs of excavation, hole digging, etc.
7. Assumption that existing plans and specifications were followed, resulting in underestimating the cost incurred because of change of plans and specifications, which changes were not recorded.
8. Assumption that all the general and overhead costs of construction appear in the construction ledgers. Some items may have been improperly charged to operating expense. Some may have never been charged at all.
9. Insufficient allowance made for higher unit costs occasioned by the existence of other plant units that obstruct work, as when overhead wires make it difficult to raise poles; or when proximity to underground pipes makes work on conduits difficult.
10. Assumption that unit costs based on work with relatively small and well trained gangs of picked men can be equaled where the work is extensive, and particularly where the work is both extensive and scattered.

Since overhead costs are indirect costs and since indirect costs are usually prorated or apportioned to different direct costs, it is inevitable that overhead costs should ordinarily be expressed as percentages. Yet the very fact that they are so expressed has often produced an impression that overhead costs are less real —

more visionary — than unit costs. This unfortunate misapprehension has received apparent confirmation because of the different overhead percentages used by different appraisers for overhead items bearing the same name.

Engineering. We have pointed out the fact that until one knows just what an appraiser has included in his unit prices it is impracticable to compare most of the overhead costs of two different appraisals. It seems desirable to add that even the same words used to designate overhead items are not always used in the same sense. The term "*Engineering*" may or may not include inspection, architects' fees, office expenses incident to engineering, etc.

In this connection it may be added that "office expenses" may or may not include interest and taxes on the office floor space. These fixed charges on office buildings, etc., are sometimes overlooked entirely. At other times they are cared for under Interest and Taxes. Again at other times they are distributed among other overhead items. Considering all such variations, it is scarcely to be wondered that percentages allowed for Engineering may vary considerably. But, if in addition to these variations we have cases where the engineers are also superintendents of construction, we have a satisfactory explanation of the fact that Engineering ranges from 3 to 10% or more.

As indicative of the errors that are being made through rather blindly adopted overhead percentages used by other appraisers without also understanding what their unit costs contain, we quote again from one of Mr. Larson's letters to us:

"Some commissions in the Southwest have been known to quote the Wisconsin Commission as putting on only 12 to 15% [for overhead costs], which they declare cover not only the items enumerated, but also promotion, discount on bonds and going value. I wish to mention this only that it may call to your mind the fact that these overhead charges are not intended to cover such items.

"It should be noted that when a telephone company purchases a switchboard the cost of a large part of the engineering on that switchboard is included in the price paid the supply company. When a gas company purchases a gas tank the cost of a large part of the engineering is paid to the supply company. Since we [the engineers of the Wisconsin Railroad Commission] place the price of these items at the amount paid by the local companies to the supply companies, this fact must be taken into account in applying our overhead charges."

We have been so frequently asked by public service commissions to explain why our percentages for overhead charges exceed those used by the engineers of the Wisconsin Railroad Commission that we found it desirable to secure from Mr. Larson a statement as to what his overhead costs included and what they excluded. The correspondence between Mr. Larson and us on this subject is quoted in full below.

Letter of Gillette to W. Larson, Dec. 8, 1914. In estimates made by your department I have frequently noticed the allowance of 12% for engineering and other overhead charges. Will you be kind enough to let me know what overhead charges are included in this 12%? I infer that it covers engineering, business management,

clerical expense, plant expense, legal expense, interest during construction and contingencies.

In the course of our investigations of the actual costs of construction for a considerable number of utility companies I find that the overhead charges, as I use them, are very much in excess of 12%, without any allowance for contingencies. However, I realize that it is the practice of many appraisers to include certain overhead charges in their unit prices. Contingencies, for example, are often placed there; likewise much of the general superintendence is also included in unit prices by some appraisers and I have done this myself in many cases. For instance, in my appraisal of the railroads for the Washington Railroad Commission, I allowed 5% for general contractor's charge, which was added to the unit prices. It had been the practice of nearly all the large railways in that State to award their contracts for large work to some general contractor on a percentage basis, the percentage being usually 5%. This contractor, who was in fact the business manager of the construction, then sub-let nearly all the work at unit prices. Now it is evident that this 5% could either be added to the unit prices or treated as an overhead charge, to be subsequently added to the grand total, and in the case of the Washington railways I chose the former method. It has always been my practice to include in the unit prices all costs of foremen and local superintendents engaged directly on the work, as well as time-keepers, etc.

In a recent investigation of a large utility company, I found the following actual percentages for the overhead charges named below:

	Per cent.
Engineering and inspection	5.0
General supervision	1.3
Clerical expense	2.0
Executive, legal and accounting dept.	1.8
Traveling	0.6
Rent and furniture expense	0.6
Stationery, postage, etc.	0.4
Miscellaneous	0.3
Total	12.0

This did not include liability insurance, as you will note. May I ask whether it is your practice to include liability insurance in the unit prices? The above 12% did not include the local foremen and time-keepers, whose costs are regarded as direct costs and therefore included in unit prices.

Since the above 12% is rather typical of a good many companies, you will see that I am at a loss to understand how you can use so low a percentage as 12% to include not only the above items, but to provide for interest during construction, contingencies and the preliminary expenses of organization.

I would greatly appreciate as detailed a reply as you care to make to these questions, for as you will realize, the precedent established by the Wisconsin Commission is largely followed by

other commissions, and I am frequently confronted with the statement that the Wisconsin Commission never allows more than 12% for overhead charges. Realizing that the practice of engineers differs as to where they place the overhead charges, that is, whether they are included in unit prices or not, I anticipate that you may have distributed your overheads to a large degree in the unit prices.

Letter of Larson to Gillette, Dec. 17, 1914. I have your letter of the 8th instant concerning overhead charges allowed by us in making valuations of physical property.

It is our custom to allow from 12 to 15% for these charges; in general, 15% is allowed on the larger properties which show a high type of construction. This item is supposed to cover engineering and superintendence during construction, general organization and legal expenses during the same period; also interest during construction and omissions, such as items not included in the inventory or items of cost which are not discovered at the time of making the valuation. These latter are rather low, as our inventories are usually made quite complete by means of co-operation of the officers and agents of the companies.

This overhead per cent. is applied to a figure which is supposed to include the total cost of labor and material, including contractors' profit, liability insurance, etc. Furthermore, it is not supposed to include any promotional profits nor is it expected to cover the item of discount on bonds; in other words the overhead charge together with the figure to which it applies will represent the actual value as nearly as may be determined of the physical property, assuming that money shall have been provided for the construction of the property.

I realize that there are plants which show higher costs for specific items than may be allowed, and it is entirely possible that in some cases where excessive difficulties are met with that engineering and allied charges may run as high as that cited by you. However, in the absence of specific information on these subjects, the valuation engineer is expected to report as the value of the property the most probable value, taking into account conditions as he finds them as compared with conditions under which he obtains his cost data.

I have had the accounts of many companies investigated under my direction, and the actual costs of specific items have been applied to the specific costs of construction, and I am led to conclude that with few exceptions 15% is high enough to cover the items mentioned in the first part of my letter.

In a recent valuation of the Milwaukee Gas Light Company, a $10,000,000 property in Wisconsin, a very careful study of the probable cost of overhead charges was made by the manager of that company and by members of our staff. This was made by several methods, one of which was to make a very liberal estimate of the force necessary to construct the property. The very highest figure to be obtained under this method was 18%, and that was based upon construction of the entire $10,000,000 worth of property before operation began; and this, as you know, is not the

way plants are constructed. We finally placed an overhead allowance of 15% in this case.

We have in this state a hydro-electric property designed and constructed by an engineer who charged for his services 10% on all items handled by him. After the entire plant was constructed the books were examined and the specific costs of construction found to be something over $1,000,000. As applied to this cost the entire charge was:

	Per cent.
Engineering and superintendence	4.51
Legal expense	0.27
Organization and office expense	2.30
Insurance, taxes and damages	1.71
Interest during construction	5.87
Discounts and commissions	0.58
Total	15.24

The period of construction was two years. It should be said that these overhead expenses include also preliminary expenses incurred some two years before construction began.

During our studies we have received statements of extremely high overhead charges and have proceeded to investigate some of them. One case which was cited by a Wisconsin corporation was that of a large power company in the west. It was reported to us that the cost of specific construction was approximately $5,000,000, while the cost of overhead charges was 49.6% of that — nearly $2,500,000. This was given with sufficient detail to appear to be good evidence. However, we inspected the details of the bookkeeping accounts and found that in the overhead had been charged such items as camp equipment, repairs and renewals, $131,000; construction equipment investment, $232,000; repairs and renewals to same, $44,000; auxiliary and operation equipment, $209,000; small tools, $22,000; dismantling plant, $4,000; boarding house loss, $9,000; suspense credits, $88,000; warehouse operation, $29,000; undistributed hauling, $41,000; employment expense and transportation, $45,000; liability insurance, etc., $54,000; watching, lighting and guarding, $38,000; hauling and erecting construction equipment, $4,000; and a number of other small items which we include in our cost of specific construction. If, now, all these items had been added to specific construction it would have raised the construction cost to a considerably higher figure and would have reduced the overhead charges a corresponding amount; the per cent. of overhead would then have been reduced to a reasonable figure.

I have cited the above simply as instances which illustrate the point I have in mind, and not at all as representing the extent of our investigation.

I have had many calls for information on the above subject, and would be very glad to have as much detailed information as possible. Some commissions in the southwest have been known to quote the Wisconsin Commission as putting on only 12 or 15%, which they declare covers not only the items enumerated, but also

promotion, discount on bonds and going value. I wish to mention this only that it may call to your mind the fact that these overhead charges are not intended to cover such items.

It has not been our practice to distribute the overhead charges to the unit prices except as mentioned above; that these prices do cover contractors' profits, liability insurance and, in a word, every item which is ordinarily included in the same to a general contractor.

It should be noted that when a telephone company purchases a switchboard, the cost of a large part of the engineering on that switchboard is included in the price paid the supply company. When a gas company purchases a gas tank, the cost of a large part of the engineering is paid to the supply company. Since we place the price on these items at the amount paid by the local companies to the supply companies, this fact must be taken into account in applying our overhead charges.

I shall always be glad to discuss this or related matters with you or other engineers, and shall be glad to have from you any statement you can make in regard to your own practice.

Letter of Gillette to Larson, Dec. 22, 1914. I have your letter of Dec. 17, relating to overhead charges.

I am interested to note that you are at present allowing about 15% for overhead charges on the larger properties which show a high type of construction.

I think that the more we study the accounting records of the large companies the more we shall perceive that most of them make inadequate charges to the construction account for what we term overhead costs.

I have just completed the analyses of overhead costs of a large utility company in New England, and find that at least 4% should be added to their book value for overhead costs (exclusive of interest). Too large an amount of overhead costs has been charged to operating expense.

What may be termed expenses of administration, including legal expense and general accounting, are very frequently charged entirely to operating expense, although upon no correct accounting theory can this be justified. This alone may amount to 2% or more of the cost of construction if properly prorated thereto. I am speaking now of companies that do a very large amount of construction each year.

Another point to be considered is the manner of prorating these overhead charges. The company above referred to has prorated all its engineering, superintendence, etc., in proportion to the direct labor, and not in proportion to the total cost of work done. Their practice is unquestionably erroneous, at least for certain of the overhead charges, and the tendency of this practice is to reduce the per cent. of overhead charges to the construction account, because the repairs and renewals involve a far larger percentage of labor than is the case with additions to the plant.

Let me thank you for your very interesting and instructive letter.

TABLE I. OVERHEADS USED IN VARIOUS APPRAISALS

STREET RAILWAY AND ELECTRIC LIGHT COMPANIES

Date of decision or appraisal	Title and citation of case or name and author of report	Basis for Determination of percentage	Detailed overhead percentages	Total overhead in per cent.
Columbus Railway & Light Company. June 8, 1906.	Columbus Railway & Light Co. vs. City of Columbus. No. 1206 in equity. U. S. Cir. Ct. S. D. Ohio. E. D. Report of Special Master. T. P. Linn.	Inventory reproduction cost.	A B I = 6.8% E = 2.7% Insurance = 0.3% I = General and miscellaneous costs.	9.8%
Puget Sound Electric Railway. June 30, 1909.	Railroad Commission of Washington, ex rel. W. H. Paulhanus, Complainant, vs. Puget Sound Electric Railway, Defendant.	Total valuation reproduction new, less the allowance for depreciation.	A B = 1.5% D I = .5 E = 4.0 G = 4.2 H = 2.7 5.2% fiscal and physical supervision and management.	18.1%
Cleveland Street Railway Company Appraisal. Dec. 16, 1909.	Cleveland Street Railway Co. Appraisal (1909). Decision of U. S. District Judge, Robert W. Taylor, in the matter of the Arbitration of the valuation of the property of the Railway Co.	Inventory reproduction cost less depreciation.	A C D E G I = 18.2% I = General expenses.	18.2%

TABLE I.— *Continued*

Chicago City Railway Company. Chicago Union Traction Company. Dec. 10, 1906.	Appraisal of Chicago Surface Railways. Report of Bion J. Arnold, Mortimer E. Cooley, and A. B. DuPont, Traction Valuation Commission to the Committee on Local Transportation of Chicago City Council.	Inventory reproduction cost.	A B C I = 11.7% D E G H = 10. % I = Incidentals.	21.7%
Metropolitan Street Railway Co. of Kansas City, Mo.	Total value approved by Judge Wm. C. Hook, and the Missouri Public Service Commission and Mr. Bion J. Arnold.		A C I .... = 11.0% Carrying charges .... = 3.0 General legal and organization expenses .... = 2.0 Cost of financing .... = 5.0 Miscellaneous costs .... = 1.4	22.4%
Appraisal of Street Railway Companies of New York, New Haven & Hartford R. R. Co. Feb. 15, 1911.	Report of George F. Swain to the Joint Commission on the Validation of the New York, New Haven & Hartford R. R. Co.	Physical cost of reproduction.	A = 5.0% E = 7.0 G = 3.0 H = 5.0 D I = 3.0 I = General expenses.	23. %
Coney Island & Brooklyn R. R.	Decision by Public Service Commission of New York.		Contractor's profit, Engineering, Organization, Incidentals } 24.8%	24.8%

TABLE I.— *Continued*

Date of decision or appraisal	Title and citation of case or name and author of report	Basis for Determination of percentage	Detailed overhead percentages	Per cent.	Total overhead in per cent.
Coney Island & Brooklyn R. R. Co.	By. Mr. Frank R. Ford.		Promotion and legal expense.	6.42	37.99%
			Property owners' consents....	4.25	
			Organization expense	2.98	
			Incidentals	4.22	
			Engineering expense	3.52	
			Contractor's profit	8.04	
			Interest and taxes	8.56	
				37.99	
Chicago Consolidated Traction Company. August, 1910.	Appraisal of Chicago Consolidated Traction Co. Report of Bion J. Arnold and George Weston. Traction Valuation Commission to the Committee on Local Transportation of Chicago City Council.	Inventory reproduction cost	A C I = 14.6% D E H = 5.8% 18% = Conducting work, furnishing equipment and brokerage. I = Incidentals.		38.4%
Detroit United Ry. City Lines.	Appraisal by Mr. Robert B. Rifenberick.		Incidentals	5.62	44.74%
			Contractors' profits	6.16	
			Liability insurance	.61	
			Builder's risk	.09	
			Architect's fees	.34	
			Cost of acquiring land	.43	
			Engineering	3.86	
			Organization	5.85	
			Carrying charges	11.06	
			Financing	10.72	

TABLE I.— *Continued*

GAS AND ELECTRIC COMPANIES

Cedar Rapids Gas Light Company. May 4, 1909.	Cedar Rapids Gas Light Co. v. City of Cedar Rapids. Sup. Ct. of Iowa.		The court rejected all claims for allowances of overhead charges.	None
Watertown Light & Power Company. Mar. 10, 1908.	Application of Watertown Light & Power Company. New York Public Service Commission, 2nd District.	Total value of improvements of combined plants.	E = 1.6% I = 1.5% — contractor's salary.	3.1%
Lincoln Gas & Electric Light Company. Apr. 6, 1909.	Lincoln Gas & Electric Light Co. vs. City of Lincoln et al U. S. Cir. Ct., D. Neb. Div. of Lincoln-Munger.	Inventory reproduction cost.	A = 2.4% C = 0.6 H = 4.7	7.7%
Crisfield Light & Power Company. Sept. 6, 1911.	Application of the Crisfield Light & Power Company — Maryland Public Service Commission.	Actual cost of plant as stated in exhibits.	E = 6.0% I = 4.9% — profit as allowed by rules of "The Builders Exchange."	10.9%
Milwaukee Electric Railway & Light Company. Aug. 23, 1912.	City of Milwaukee v. Milwaukee Electric Railway and Light Co. Wisconsin R. R.. Comm.	Cost of plant from inventory appraisal.	A B = 4.0% C D = 2.0 E = 3.0 H = 3.0	12. %
La Crosse Gas & Electric Co. Nov. 17, 1911.	Application of La Crosse Gas & Electric Company to increase rates. Wisconsin R. R. Comm.	Tentative inventory reproduction cost.	A B = 5.0% E = 4.0 C D H = 3.0	12. %
Beloit Water, Gas and Electric Company. July 19, 1911.	City of Beloit v. Beloit Gas, Water & Electric Co. Wisconsin R. R. Comm.	Tentative inventory reproduction cost.	A B = 5.0% E = 4.0 C D H = 3.0	12%

TABLE I.— *Continued*

Date of decision or appraisal	Title and citation of case or name and author of report	Basis for Determination of percentage	Detailed overhead percentages	Total overhead in per cent.
Consolidated Gas Co. of Long Branch. July 25, 1911.	Re: Consolidated Gas Company of Long Branch.	Inventory reproduction cost.	A B = 5.0% E = 4.0 C D H = 3.0	12%
Ripon Light & Water Company. Mar. 28, 1910.	City of Ripon vs. Ripon Light & Water Co., Wis. R. R. Com.	Tentative inventory reproduction cost.	A B = 5.0% E = 4.0 C D H = 3.0	12%
Madison Gas & Electric Company. Mar. 8, 1910.	State Journal Printing Co. v. Madison Gas & Electric Co. Wisconsin Railroad Commission.	Cost of the Physical value of plant.	A = 5.0% E = 4.0 C D H I = 3.0 I = Casualty insurance.	12%
Consolidated Gas Co. May 18, 1907.	Consolidated Gas Company v. City of New York. U. S. Cir. Ct., S. D., N. Y. Report of Arthur H. Masten, Master in Chancery.	Value of plant.	A E I = 12.5%. I = General expenses.	12.5%
People's Gas Light & Coke Company of Chicago. Apr. 17, 1911.	Report of Wm. J. Hagenah to the Gas Sub-Committee of the Chicago Council Committee on Gas, Oil & Electric Light.	Based upon cost of reproduction covering a period of ten years and divided into 3 periods for doing the work. (See Note.)	A B = 4.7% C D = 2.0 E = 4.7 F = 0.3 H = 5.3	17%

TABLE I.— *Continued*

Central Hudson Gas & Electric Co. July 16, 1912.	Application of Central Hudson Gas & Electric Company. New York Public Service Commission for the Second District.	Total of tangible property.	A B = 6.7% E = 2.9 I = 7.9 = Other intangible property.	17.5%
Public Service Gas Company. Dec. 26, 1912.	Re: Rates of Public Service Gas Co. (Passaic Gas Case) Bd. of Pub. Utility Comm. of N. J.	Inventory appraisal.	A B C F H I = 11.0% E = 6.6 I = Liability for accidents and damages.	17.6%
Kings County Lighting Company. Oct. 20, 1911.	John G. Mayhew et al. v. Kings County Lighting Co. New York Public Service Commission, First District.	Total value of plant.	E F = 4.8% A B H I = 13.8% I = Incidentals and general contractor's profits. 5.7% preliminary development.	24.3%
Queens Borough Gas & Electric Company. June 23, 1911.	Re: Rates of Queens Borough Gas & Elec. Co. Report of E. G. Connette of the Transportation Department to the Commission. New York Public Service Comm. First District.	Total value of plant as found by Mr. Connette.	A B H I = 16.3% C D E F = 13.7% I = Incidentals and general contractor's profits.	30.%
RAILROAD COMPANIES				
Washington Railroad Appraisal. June 30, 1907.	Washington Railroad Appraisal. Reports of Halbert P. Gillette upon the valuation of the Northern Pacific R. R. Co. and upon the valuation of the Great Northern Ry. Co. to the Washington R. R. Commission.	Cost of reproduction of plant, except land and equipment.	E = 5.0 F = 1.0 D I = 1.0 I = General costs.	10.5%

TABLE 1.—*Continued*

Date of decision or appraisal	Title and citation of case or name and author of report	Basis for determination of percentage	Detailed overhead percentages	Total overhead in per cent.
Appraisal of New York, New Haven & Hartford Railroad Company. Feb. 15, 1911.	Report of George F. Swain to the Joint Commission on the Validation of the New York, New Haven & Hartford R. R. Co. Report of Joint Commission.	Cost of road; present valuation with no allowance for depreciation.	A = 1.8% D = .8 E = 7.8 H = 1.8 1.0 = other expenditures.	13.2%
Wisconsin Railroad Appraisal. June 30, 1903.	Wisconsin Railroad Appraisal. Report of Prof. Wm. D. Taylor to State Board of Assessment of Wisconsin Tax Commission.	Cost of reproduction, present condition.	A B D = 3.6% C = 1.3 E = 3.2 H = 5.8	13.9%
South Dakota Railroad Appraisal. June 30, 1909.	South Dakota Railroad Appraisal. Report of Carl C. Witt, Engineer, to the Board of Railroad Commissioners of So. Dak.	Total value after allowance for depreciation.	A B D = 4.0% E = 3.2 H = 5.8 Other expenses = 1.1	14.1%
Appraisal of the Minnesota Railroads. June 30, 1907.	Report of Dwight C. Morgan to the Railroad & Warehouse Commission of Minnesota.	Total cost of physical reproduction, less depreciation; but including overhead charges.	A B D = 3.4% E = 8.7 H = 4.9	17.0%
Appraisal of the Michigan Railroads. 1900–1901.	Report of State Board of Assessors to the Board of State Tax Commissioners of Michigan.	Inventory reproduction cost with no allowance for depreciation.	A = 3.2% C = 1.5 D = .4 E = 3.1 H = 10.8	19.%

TABLE I.— *Continued*

Buffalo, Rochester & Eastern Railroad Company. Aug. 7, 1911.	Application of Buffalo, Rochester and Eastern Railroad Company, New York Public Service Commission, Second District.	Estimated total cost of construction.	A = 3.0% E = 10.0 H = 5.4 B D I = .9 C G H = 15.0	34.3%
TELEPHONE AND TELEGRAPH COMPANIES				
Cumberland Telephone & Telegraph Company. Apr. 25, 1911.	Cumberland Telephone & Telegraph Co. v. City of Louisville.		The court says that "overhead charges" are covered by the present value of plant.	None
Lodi Telephone Exchange. May 7, 1913.	E. W. Johnson et al. v. Lodi Telephone Exchange. Wis. R. R. Com.	Inventory appraisal.	A B = 5.0% E = 4.0 C D H = 3.0	12%
Pioneer Telephone & Telegraph Co. Jan. 10, 1911.	Pioneer Telephone & Telegraph Co. v. Westenhaver et al. (Oklahoma Telephone Rates) Sup. C. D. Okla. Hayes, J.	Inventory reproduction cost of plant.	A B = 10.% E = 5.%	15%
WATER COMPANIES				
Artesian Water Co. 1902	Proceedings of the Legislative Council, City of Memphis, respecting purchase of Artesian Water Plant and reports of Committee on Water, Hydraulic Engineers, Certified Accountants.	Entire reproduction cost less cost of land.	A H I = 10% I = Expenses.	10%
Antigo Water Company. Aug. 3, 1909	Hill v. Antigo Water Co., Wis. Railroad Commission.	Inventory reproduction cost.	A B = 5% E = 3% H = 2%	10%

TABLE I.— *Continued*

Date of decision or appraisal	Title and citation of case or name and author of report	Basis for Determination of percentage	Detailed overhead percentages		Total overhead in per cent.
Des Moines Water Co. Sept. 16, 1910.	Des Moines Water Co. v. City of Des Moines. No. 2468 in equity, U. S. Cir. Ct. S. D. Iowa, C. D. Report of George F. Henry, Master in Chancery.	Total physical reproduction cost without including "Going Concern Value."	A B D H I = 6.9% E = 6.9%	Made by Co's. Engineer	13.8%
			A B = 3.5% E = 5.5 D H I = 4.8 8.4 Contractor's profits. I = General expenses.	Made by City Engineer	22.2%

OVERHEAD COSTS

Table I gives detailed overhead costs used in various appraisals of public utilities. The different items included under "Detailed overhead percentages" are as follows:

A — Engineering.
B — Supervision.
C — Organization.
D — Legal expenses.
E — Interest charges.
F — Taxes.
G — Brokerage and discount.
H — Omission and contingency.
I — Miscellaneous (stated).

Accounting Terms. Every engineer should acquaint himself thoroughly with bookkeeping and accounting. Hatfield's "Modern Accounting" is an excellent work on the theory of accounting and the terms used in accountancy.

As engineering has suffered from lack of knowledge of accounting practice, so accountancy has suffered from lack of engineering knowledge of cost analysis. Many terms used in accounting will ultimately be revised and given greater definiteness as a result of engineering analysis.

Gross Operating Earnings or Revenues are the total income from the sales of the product of a plant or property.

Operating Expenses are the costs of operating and maintaining the plant. Usually operating expense includes taxes, but often taxes are not included in the so-called operating expenses, and are treated as "fixed charges." Current repair expenditures are always included, but depreciation annuities to provide for future renewals are seldom included. However, there is no fixed practice as to the treatment of depreciation charges (see Chapter II).

Net Earnings are the balance remaining from gross earnings after deducting operating expenses. Net earnings are sometimes crudely designated as profits. Unless taxes and depreciation annuities are included in operating expenses, the net earnings should properly be called *apparent or ledger net earnings.* But if taxes and adequate depreciation annuities are deducted, the balance may be called *true or actual net earnings.* Very few ledger accounts show true net earnings and are therefore apt to be deceptive.

Fixed Charges, as the term is commonly used, includes interest (on funded debt, real estate mortgages, and floating debt), contractual sinking fund requirements, and accrued taxes (if taxes are not carried as an operating expense). Also it is occasionally the practice to include depreciation annuities as a part of fixed charges. The term "capital costs" is often used to designate interest, depreciation and taxes.

Dividends are the so-called "profit" distributions to stockholders.

Surplus, as the term is commonly used, is the balance remain-

ing after deducting fixed charges and dividends from "ledger net earnings."

While, as above stated, it is the practice of many companies to provide for bond sinking fund requirements as a part of Fixed Charges, other companies treat the matter differently and deduct the annuities for bond sinking funds from Surplus. Some companies also make a similar deduction from Surplus to provide annuities for a *Replacement Reserve,* instead of providing for such a reserve in the form of a depreciation fund considered as part of the operating expense. It is important, therefore, not to assume that all actual renewal expenditures will necessarily be found under the Maintenance Expenses, that is, among operating expenses. Where a Replacement Reserve is provided for out of Surplus, it is a common practice to pay for all heavy renewals out of this Reserve, in which case such payments never appear as an operating expense. Because this is done it should not be assumed that maintenance expense does not contain a considerable expenditure for true renewals, for it usually does. In brief, both the maintenance expenses and the credits to the Replacement Reserve should be analyzed to ascertain the total actual expenditures for renewals.

In providing a Replacement Reserve it is not uncommon to estimate as follows what should be placed annually in the reserve: Take 20 or 25% of gross annual earnings, and deduct therefrom the actual annual maintenance expenses of the previous year; the balance is the amount to be put into Replacement Reserve.

While this forms a good rough and ready rule in many cases, it is apt to lead to serious error in a given case. A much more rational method, where the appraised value of the plant is known in detail, is to estimate the annual depreciation of each class of plant units, take the sum total and deduct therefrom the average annual expenditure for renewals that have been charged to maintenance during the previous year; the balance is the sum to set aside in the renewal reserve. (See Chapter II.)

Interest is the payment for the use of money. The payment for the use of real estate is *rent,* but the term rent is often applied also to payment for the use of other sorts of capital except money.

Interest includes not only a return for the use of money but insurance against risk and compensation for at least some proprietary supervision. Interest may also include compensation for taxes paid on money loaned.

Economists assign a single cause for the payment of interest, namely, the preference of present goods to future goods. Although this is the immediate cause of interest, the statement of desire as a cause is merely a platitude that yields no deeper insight into the phenomenon than was already had. We must look back to the mediate or remote causes. There are many motives that lead to borrowing and the consequent payment of interest. The most common motive in the present age is the desire to command labor and through successful command to secure profit. Interest has thus become a device for selecting the highest officers of the in-

dustrial armies. Interest on invested capital has heretofore proved to be an economic instrument of much greater efficiency than election, appointment, examination or other device used to select leaders.

Interest rates in America range from 3 to 12% depending largely on the risk involved, but also depending on the size of the loan and the amount of proprietary supervision on the part of the lender. The general average rate is between 5 and 6%, where risks and proprietary supervision are relatively small. It should be remembered, however, that there is always danger of error in applying any "general average" factor of this kind in a cost problem. Each case should be studied carefully as a problem in itself.

Profit is the excess of selling price over cost.

We have just seen that "cost" is sometimes used in a sense that does not include "sacrifice cost." When so used "profit" includes "sacrifice costs," such as proprietary supervision and interest on the proprietor's capital. There is no unanimity of practice respecting the use of the word profit, for obviously its significance depends upon the definition of the word cost.

The present tendency is to include in cost a charge for the proprietor's time as well as rental on his real estate and interest on his other capital and development cost. Then profit covers only the income that constitutes a reward for superior judgment, management, luck and insurance against risks and depreciation not included in the operating expenses.

Where the word profit occurs in a law or in a contract, it is evidently possible for dispute to arise unless the word cost is very fully and carefully defined.

Normal Return on capital is the sum of normal interest and normal profit. Normal interest rate may be designated as a bond or mortgage interest rate on property similar to that in question, where there is a substantial equity above the bond.

Normal profit covers both a normal return for proprietary supervision and for insurance against all risks not provided for in the operating expenses. Among these risks are loss of income arising from general or local business depressions, loss of income from public enactments, and loss of income from direct and indirect competition. Functional depreciation may also be regarded as one of the forms of risk, and should be provided for in the profit rate if not already provided for as an operating expense. Totaling up we may have some such statement as this:

	Per cent.
Normal interest rate	5
Normal profit rate —	
Proprietary supervision	2
Functional depreciation	2
Insurance on permanency of income	1
Total normal return rate	10

These percentages are here given merely for illustration. An interest rate, such as 5%, contains elements of proprietary supervision and insurance.

Mistakes in the use of rates for capitalizing expenses or incomes are so common as to be almost universal. Let two things be remembered and many of these mistakes will cease: First, that the normal return rate and not a bare interest rate must be used in capitalizing. Second, that the normal return rate depends in part upon what exists in the operating expenses in the form of proprietary supervision and functional depreciation.

A normal return rate is what public service commissions usually aim to allow a company to earn, and they commonly call it a "fair return rate." Although it is customary to estimate a "fair return" as a percentage on an investment, it is perhaps better to proceed as follows: Allow an ordinary interest rate, say 5 or 6% on the investment, and thereto add a percentage (for proprietary supervision and risk) of gross annual income, say 8 to 12%; the sum of these two constituting a "fair return" for capital, proprietary supervision and risk. Suppose, for example, the ratio of gross income to capital investment is 1 to 5 and that 10% of the gross is allowed for proprietary supervision and risk; then this is equivalent to 2% on the capital investment, which added to 6% interest on the capital gives a fair return rate of 8%.

Capitalized Value. The capitalized or discounted value of a property is the present worth of its prospective net earnings. The word value is commonly used instead of capitalized value when reference is had to the commercial worth of productive property.

The process of deriving the present worth, or value, by dividing annual net earnings by an interest rate is called *capitalizing* the net earnings. If the annual earnings are $12,000, and if the interest rate is 6%, the capitalized value is $12,000 ÷ 0.06 = $200,000.

Capitalized Cost. The capitalized cost of a property is the equated or true average annual cost divided by the interest rate. If the true average annual charges, including interest, operating expense, depreciation annuity, etc., are $30,000 and the interest rate is 6%, the capitalized cost is $500,000. The first cost of a plant plus its capitalized annual operating expense, inclusive of depreciation and taxes, obviously amounts to the capitalized cost of the plant.

Equated Annual Costs. The annual costs of repairs and renewals are seldom uniform, but tend to rise in an irregular "curve" as a plant grows older. The process of finding a true economic average annual cost is called *equating* the cost. This can be done correctly only by a sinking fund method of calculating wherever capital is susceptible of being invested so as to yield interest. Notwithstanding this seemingly obvious fact there are men so little trained to logical reasoning that they deny the necessity of using sinking fund formulas or tables in calculating either average annual costs, property values or depreciated plant values.

Before a rational comparison can be made between alternative plants, it is essential to express all costs either as equated annual costs or as capitalized annual costs that have been equated. To *equate*, as here used, means to secure a true average by a sinking fund method of calculation. When, for example, the cost of re-

pairs is irregular, varying from year to year, no rational comparison of repair costs can be made until they are equated to an average annual amount. This cannot be accurately done by adding all the annual repairs together for a term of years and dividing by the number of years in the term. The correct process is as follows:

Calculate the total cost of repairs of the first year at compound interest up to the end of the last year of economic life of the unit in question. Calculate similarly the cost of repairs of the second, the third, etc., years up to the end of the last year. Add all these compounded costs together and multiply by the annual deposit in a sinking fund which started at the beginning of the life will redeem $1 at the end of the life of the plant unit. The product is the equated annual cost of repairs.

If the annual cost of repairs is actually uniform, year after year, throughout the life, say $100, the above given rule gives $100 as the result, thus checking the correctness of the rule.

If the repairs all come at the very end of the life, and thus constitute an entire renewal, obviously the rule gives the correct answer, namely, the sinking annuity required to redeem the investment at the end of the life.

Common Errors in Capitalizing Values. The capitalized value method is used not only in estimating the value of land, of water rights, of franchises, and of all property that has a prospective earning capacity, but it is used by engineers in comparing the relative plant designs and plant locations. In spite of such extensive use of this method, it is probably more often used erroneously than correctly. To use it correctly there must be complete understanding of the interrelation of all the factors, and this is rarely had.

To begin with the percentage used in capitalizing should never be an ordinary interest rate, unless the annual costs have been equated (as above described). To capitalize an annual income by dividing by an ordinary interest rate, say 6%, tacitly assumes that the income will be perpetual, or if not perpetual that due deduction has been made in form of a sinking fund annuity.

In a recent address to engineering students a professor said that the average engineer is worth $55,000 more to society than if he had no engineering education. It was stated that the average "technically-trained graduate of our engineering colleges earns annually, on the average, at least $3,000." This is stated to be $2,200 in excess of the average earnings of a "trade-trained man."

The $2,200 annual gain was capitalized at 4%, giving $55,000 as the "increased potential value to the community" resulting from the engineering training received by each engineering graduate.

Not only is this an incorrect appraisal of "increased potential value to the community" but it is not a correct appraisal of the worth of an engineering education to the average engineer.

If the duration of the average engineer's earning capacity is, say, 40 years, the present worth of an average $2,200 gain is not

$2,200 ÷ 0.04 = $55,000, but $2,200 ÷ (0.04 + 0.01) = $44,000. The 1% is added to the 4% because the 1% gives the amount of the annuity required to amortize the value in 40 years.

In another form the error of tacitly assuming a perpetual life when capitalizing a value occurs whenever any one fails to allow for functional depreciation due to inadequacy or obsolescence. If allowance is not made for this factor by means of an adequate depreciation annuity as a part of the equated annual operating expenses, it should be made by adding the depreciation annuity rate to the interest rate to get the percentage rate used in capitalizing the annual cost. Throughout Wellington's admirable treatise on "The Economic Theory of Railway Location" the error is made of ignoring functional depreciation when capitalizing the operating expenses of alternative railways lines.

Another common error in capitalizing values is to use bond interest rates, say 4 to 5% instead of normal (or "fair") return rates, say 10%. Consideration of the facts previously brought out in our discussion of "fair return rates" will make it clear why such rates should be used in capitalizing net earnings to arrive at commercial values.

In this connection it should be observed that it is immaterial whether every item of insurance (commercial risk, fire, bad debts, etc.) be treated as an expense or whether it be converted to a percentage of the plant value and added to the "fair return rate" to get the capitalization rate, but one or the other of these alternatives must be adopted. Similarly as to the item of proprietary supervision, it must either appear in toto in the operating expenses, which rarely happens, or it must appear as part of the percentage rate used in capitalizing the net income. Many a plant has been commercially appraised at too high a value because of failure to understand the principles just stated. This is particularly the case with small plants where proprietary supervision is usually so large a factor relative to the total annual cost.

Alternative Plant Method of Valuation. A criterion of the value of a given thing is the cost of securing the next best alternative that will perform the same function. The only limitation in the application of the alternative plant method of valuation may be stated thus: The market price of the product of the plant must be such that its net earnings give a normal rate of return on the cost of the alternative plant. Average prospective net earnings capitalized at the normal rate of return give the value of a productive property. It is conceivable, of course, that an alternative plant might cost so much that its product could not be marketed at a price that would yield a normal return on the cost. Obviously, then, the value of the plant could not equal its cost. But within this limit, the alternative plant method of valuation is strictly applicable.

It follows, then, that if the gross earnings are not affected by the substitution of an alternative for any part of a plant, the correct criterion of the value of a part of a plant is found by the rule given below in italics.

Assuming gross-income to be unchanged by substituting an alternative part in a plant, the value of any part is the first cost of its most economic alternative plus the capitalized difference in their respective average annual operating expenses.

Expressed algebraically this rule is:

$$v = C + \frac{E - e}{R}.$$

This formula also gives the depreciated value of a plant unit (see page 100). The derivation of the formula follows.

C = first cost of the most economic alternative plant.

c = ditto of existing plant.

E = average ("equated") annual operating expense inclusive of repairs, natural depreciation and taxes, but exclusive of functional depreciation and interest, for the most economic alternative plant.

e = ditto for the existing plant.

f = sinking fund rate per cent. of annual functional depreciation.

G = average annual gross income with the alternative plant.

g = ditto with the existing plant.

R = a capitalization rate = $r + f$.

r = interest rate = "fair return rate."

V = value of most economic alternative plant.

v = ditto of existing plant.

$$V = \frac{G - (E + f\,C)}{r} \qquad \text{(1)}$$

$$v = \frac{g - (e + f\,c)}{r} \qquad \text{(2)}$$

$$v\text{-}V = \frac{(E - e) + f\,(C - c) - (G - g)}{r} \qquad \text{(3)}$$

If the gross income is the same for both plants, then $G = g$; but in order that either plant shall have any commercial value as a working plant it must produce gross earnings sufficient to pay its operating expenses and fixed charges. Assuming this to be the case, and that all earnings in excess of this requirement are "going concern value," it follows that $V = C$, or that the value of an alternative plant is its first cost. Then substituting C for V in Equation (3) and remembering that $G - g = O$, we have:

$$v = C + \frac{(E - e) + f(C - v)}{r} \qquad \text{(4)}$$

If the existing plant were sold at its value v, then to the purchaser its "first cost" would be c, or $v = c$, whence:

$$v = C + \frac{(E - e) + f(C - c)}{r} \qquad \text{(5)}$$

$$v = C - \frac{E - e}{r + f} = C + \frac{E - e}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Equation (6) gives the depreciated value of a plant unit, under the condition that a new plant unit yields the same output as the old plant unit. This same equation is derived in another way in Chapter 11.

Equation (4) is the equation to use when the value of land, water rights, or the like is to be calculated, and there v includes not only the value of the existing plant but the value of the land, water rights or the like associated there with it and indispensable thereto.

Value of Plant Location of Right of Way and of Water Rights. The value of a right of way, or of a plant site, or of water rights, of coal or indeed of any land entity is correctly calculable by the alternative plant method (Equation 4), just discussed. But in making the calculation it should be remembered that it is always assumed that the gross income will be sufficient to pay a "fair return" on the value thus determined.

In the case of farm or mineral products there is ordinarily an "open market" wherein the prices of the products are established. Given the unit prices, and knowing the number of units that will be produced annually from a given piece of land, the average annual gross income is readily estimated. Equation (2), above given, determines the value of the plant inclusive of land, water rights, coal or whatever *capital* is involved in the production. Then the total value thus ascertained, less the depreciated value of the plant, is the value of the land, water rights, coal, or other land entity. Why, then, is it necessary in such a case to use Equation (4)? It is not, if all the data are available, but one of the difficulties inherent in such problems is the determination of the probable gross income. But it is usually easy to ascertain what an alternative plant with the necessary land would cost. If this can be done, Equation (4) offers a simple solution of the problem.

To illustrate:

Certain water rights are owned, leased or otherwise controlled by a water company. Their value is in question. The appraiser must arrive at the value by considering the most economic alternative sources of water. Suppose the water company has a watershed from which it secures a water supply that is impounded near the city and is delivered by gravity. Two alternatives may present themselves: (1) Another but more distant watershed from which a gravity supply is obtainable, and (2) a nearby river from which the water must be pumped and filtered.

An estimate is made of the first cost and operating expense of each of these two alternatives, and of the corresponding operating expense of that part of the existing plant that would be displaced were either of the alternatives used.

The following example will illustrate the solution of such a prob-

lem. Let the first cost of the alternative gravity system be estimated to be as follows:

Watershed rights, 10,000 acres at $10 per acre....	$100.000
Pipe line right of way, 16 miles	16,000
Headworks, supply pipe line and reservoir	460,000
Total	$576,000
Overhead charges and contingencies 30%	172,800
Total first cost	$748,800

Let the yearly operating expense, including maintenance, depreciation and taxes, be $23,000 on this alternative water supply system. Let the corresponding first cost of the existing supply system be:

Headworks, pipe line and reservoir	$400,000
Overhead charges and contingencies, 25%	100,000
Total first cost	$500,000

Let the yearly operating expense be $15.000.

Then, if a normal return rate is 8%, the value of the existing supply system *including* its water rights and lands associated therewith is $748.000 + ($23,000 — $15,000) ÷ 8% = $848.000. Since this includes the $500.000 first cost of the existing supply system, it follows that the water rights (and lands associated therewith) of the existing system are worth $848.000 — $500,000 = $348.000.

Four important points are to be noted: (1) The estimated cost of acquiring watershed rights must be included in the first cost of the alternative water supply system but must be excluded from the first cost of the existing water supply system.

(2) The interest rate used in capitalizing the difference in operating expenses — 8% assumed in this case — must be a normal return rate on such an investment. It must not be a bare interest rate on well secured loans. If functional depreciation is not provided for in the operating expenses it should be provided for by increasing the normal return rate, and this is preferable where the water right values themselves are depreciable.

(3) Estimated allowances for contingencies should ordinarily be considerably higher for a plant not built than for one in existence, particularly where engineering and accounting records of the existing plant are fairly complete.

(4) If water is brought from a great distance a larger distributing reservoir is needed in or near the city than if the supply line is short. Breaks in a long line are more likely to occur, and the fire risk correspondingly increased if the distributing reservoir is small.

Where an alternative supply system involves pumping and filtration or other treatment of the water, the annual expenses when capitalized may become very great, and will correspondingly increase the value of the water rights of an existing pure, gravity supply.

For an extended discussion of water right valuation see three articles by Halbert P. Gillette in Engineering and Contracting, Apr. 17 and Dec. 4, 1912, and Sept. 1, 1915.

For a discussion of the real or commercial value of a plant site or a railway right of way, see "Some Important Considerations in Right of Way Valuation" by Halbert P. Gillette, in Engineering and Contracting, June 30, 1915.

Value of Attached Business. The value of any property, as above stated, is the present worth of its prospective net earnings. It is often desirable to segregate this value into two parts which are variously designed; as, (1) "tangible" and (2) "intangible," (1) "physical" and (2) "non-physical," (1) "plant" and (2) "good will," (1) "tangible property" and (2) "going concern value," etc. In the case of public service corporations the non-physical value is often called "franchise value."

In every case the procedure is first to capitalize the prospective equated net earnings and therefrom deduct what is regarded as the "value" of the physical or tangible property, the remainder being the non-physical value or the value of the attached business. But it should be remembered that this segregation is justifiable only on the hypothesis that the existing physical property — the plant, etc. — is replaceable by an equivalent, without changing the gross income.

Having calculated the value of the existing physical property by the alternative plant method, as above described, deduct the physical property value from the capitalized value of the prospective net earnings and the balance is the "value of the attached business" or, more properly, the value of the business in excess of that needed to yield a fair return on the value of the physical property.

Often, but quite improperly, the cost of developing or establishing a business is spoken of as "going value"; it may properly be designated as "going cost," but it certainly is not value.

It is important to realize that many of the items of physical or tangible cost are quite as non-physical or intangible as those commonly classed as non-physical. Thus after a plant has been built there is no physical thing in the plant that can be designated as "interest during construction," or as "cost of construction accounting," or as "cost of engineering," which are all regarded as parts of the total physical cost. These are quite as non-physical or intangible in fact as the "cost of attaching the business," which is classed as intangible. Hence the terms physical and non-physical, tangible and intangible, at bottom denote no fundamental difference in the costs or values to which they relate, but are merely convenient expressions for classifying costs or values, which classification each appraiser adopts rather arbitrarily for his purposes, but in which few appraisers are consistent with their own theories. Men are so commonly deceived by words that it is not unusual to find engineers, public utility commissioners and judges floundering in a morass of quibble as to whether a given item of cost or value should be classed as "tangible" or "intangible." In

truth no cost is either physical or tangible except in relation to the money with which it was paid for. Mental services relate to things that affect the senses, but once such services have been performed and paid for no tangible substance may remain to indicate the fact. It is pure sophistry, therefore, to argue that the service rendered by a timekeeper on construction work is a whit more entitled to be called tangible than is the service of a man who attaches customers to a plant by soliciting or advertising.

Rate of Fair Return. Public service commissions have adopted the expression "rate of fair return" to denote the percentage of annual net operating revenue allowed by them upon the appraised value of a public utility property. The "net operating revenue" is the balance remaining after deducting from gross operating revenue the operating expenses, taxes and depreciation annuity.

Public service commissions have commonly allowed 6 to 8% as a "fair return rate." Few decisions have indicated that much study has been given to the subject of the "fair return rate." The Wisconsin Railroad Commission analyzes the rate into two elements: (1) The interest rate and (2) the profit rate. Thus a 6% interest rate plus a 2% profit rate give an 8% "fair return rate." The profit (2%) presumably covers risk and leaves a margin for what may be called proprietary reward.

Adam Smith in his "Wealth of Nations" (written about the time of our Revolutionary War) speaks of the normal "profits" of manufacture, merchandising, etc., as being double the normal interest rate, or about 12%, but he used the word "profit," as many people still use it, to include a normal interest on the investment.

A rate of fair return may be analyzed into three elements:

1. Interest on well secured capital.
2. Insurance against risks covered neither in the operating expenses nor in the interest.
3. Reward for proprietary supervision.

Ordinary interest rates contain at least some insurance against financial risks, but this insurance is relatively slight in the bonds of large, well established companies.

A 4.5 to 5% interest rate usually includes comparatively little risk insurance and very little proprietary supervision.

Risk insurance should always be considered in connection with the depreciation annuity, although the two rarely have been viewed together as parts of one whole. A depreciation annuity is largely an insurance against obsolescence and economic inadequacy. Hence if little or no provision is made for these factors in the form of a depreciation fund, it follows that the "rate of fair return" should be made correspondingly greater. Almost without exception, however, this important matter has been disregarded in establishing rates of "fair return." The same rate has repeatedly been applied to two similar companies, one of which set aside a liberal depreciation reserve while the other provided no reserve at all.

It has often been said that the element of risk is largely elim-

inated under public regulation of rates. But this is not true. In nearly every state the municipalities are free to build competing plants, and they often do so. Wars and other causes of "hard times" continue to make every business somewhat hazardous. Then there is the ever present hazard of poor management. Let bad judgment be used in making additions to or changes in the plant, and much of the profit may be absorbed in "development cost," leaving little or nothing for dividends. Against these and other risks the public guarantees nothing. The rates paid for the service are assumed to provide the insurance. It is true that rates found to be inadequate may be raised, but the public ill-will that usually follows a rise in rates is often very costly to a company, even where it is practicable to increase rates.

Every public utility plant that has been properly designed for a growing community, is more than adequate for its present needs, in at least some of its parts. This is inevitable, for the engineer plans not merely for today, but for several years in advance. Let something occur to reduce the rate of growth considerably and it will often be found impracticable to charge rates that will yield a "fair return" on the entire investment until the old rate of growth is resumed. There are plants that are badly "overbuilt"—too large for the present population—and they do not and can not yield a "fair return." To insure against such risks as this, a higher rate of return must be provided for plants in general.

A common sophistry is found in the arguments of those who hold that 6% is a "fair return rate" in the case of old and successful companies, even if not sufficient in the case of new companies. This sophistry is perhaps best exposed by showing what would happen were the securities of all utility companies owned by one company or person. Then, it is clear, the deficits in fair return suffered by the unfortunate companies would have to be counterbalanced by the surpluses earned by the remaining companies, else the total net income would fall short of being a "fair return." Wherever the item of insurance rate enters an economic problem, it must be applied as an annual percentage to a large number of similar units. Hence if the rate of "fair return" includes insurance against certain risks, as it should, it is manifestly unsound to confiscate the risk insurance in the case of a financially successful company by reducing its rate of return.

Although the element of risk insurance may be discussed by itself, it is closely associated with the third element in the "fair return rate," namely the reward for proprietary supervision, that is the reward to the owners of the property for exercise of judgment and the courage of their convictions. In nearly every utility company there is at least one stockholder upon whose judgment a very great deal depends. He is the financial leader to whom men are attracted because of his recognized ability at making his investments "make good." He may not be, and often is not, the active manager of the company, but he frames its larger policies and he directs their execution. Associated with him are

other investors, and his financial power usually depends largely upon them. Such a leader, if successful, is unquestionably entitled to reward. He must share the reward with his financial associates, else they will flock to other leaders. The reward is the profit in excess of normal interest, and it is, of course, so intertwined with the risk insurance element as not to be precisely separable.

Altogether too much stress has been put upon the risk element and too little upon the proprietary reward element in discussions of fair return rates. That a stockholder should be rewarded for what appear to be entirely the acts of other men has not seemed equitable. Whether it is ideally equitable or not is hardly germane. The election of public officials, for example, is not an ideal process of selecting such officials. We may well form ideals, but we should not hastily condemn all that fails to fit the mold of perfection. So, while it may not be a scheme without flaw to reward all stockholders because some few greatly merit reward, we can not escape doing so as long as the financial world is as it is. Furthermore, let us beware of denying merit to the man who is merely capable of discovering merit. The little stockholder who saw in James J. Hill a great railway man is perhaps entitled to reward for so seemingly small a thing as his vote of confidence. At any rate, the time has not yet come to declare the stock company system of co-operative risk and profit a failure. It continues to bring to the front a goodly supply of strong men, who, with all their frailties, are seemingly the fittest to lead.

In a small plant the proprietor often draws little or no salary, but looks to the dividends on his stock for his main compensation, even though he devotes considerable time to the general management of the plant. Where this is the case the rate of fair return should far exceed the ordinary allowance of 7 to 8%. Moreover, it should be remembered that the risk insurance element is usually greater for a plant serving a small city than for one serving a large city. The closing down of a few large industries in a small city may seriously reduce the net earnings of a utility plant that serves them. The higher rate of interest that small companies pay on their bonds indicates, in part, the greater risk involved.

In establishing what a rate of fair return should be it is customary to show, by the testimony of local bankers and real estate men, what the prevailing rates of interest on mortgages are. Also it may be shown that such a business as banking itself commonly yields a return of 8% or more on the invested capital and surplus. The average "return" earned by national banks in America has exceeded 9% for many years.

It is also well to establish what the normal "profits" from various classes of business enterprises are. To do this some well-known auditing firm may testify as to their experience, and without naming individual cases may submit lists of examples of "profits" normally earned by various classes of companies whose books have been audited by them. (See Table I A, p. 44.)

A rate of fair return for a public utility company should be one

that will attract new capital for additions and improvements. If the rate is too low capital will flow into other fields. But, although it is common to speak of capital as if it were a thing impersonal in the extreme, money is, in fact, an order to command labor; and the commission to execute the order is virtually given to some capitalistic leader. It is of prime importance that the leader be progressive. Capital will doubtless flow at low rates into long established, conservatively managed businesses in old communities, but the fact that it does so is no evidence that low fair return rates should be fixed. Better far, for the sake of ultimate low unit cost, is a higher rate of return that will fire the imagination of a progressive financial leader. Under the guidance of such a man business can be made to thrive and, thriving, the unit charges for product or service will decrease almost automatically.

It is fast becoming evident that there are grave defects in the plan of allowing only a fixed rate of return on the cost or value of a plant. Proprietary brains deserve reward not for what is expended in plant construction, but for what is saved. Ultimately, perhaps, a normal interest rate of say 6% will be allowed upon the investment in a utility plant, plus a profit that rises as the unit charge for the service to the public falls. The sliding scale of dividends allowed to certain gas companies, as in Boston, illustrates the trend toward a more rational rate-making theory. For each 5 cts. per thousand reduction in the price of gas, the dividend rate on the stock is permitted to rise a stated fraction of 1%.

Some years ago we suggested the plan of periodic rate fixing, under which the rates of charge would not be lowered by public act for a term of years, and during which a company would be like the owner of a patent, entitled to earn all that could be earned. Recently the rates of the New York Telephone Co. were fixed by the public service commission for a period of three years. While this is much too short a period in most cases, it illustrates the point and may forecast a trend.

TABLE IA. RETURN ON INVESTMENT IN SUNDRY MANUFACTURING CORPORATIONS NOT UNDER GOVERNMENTAL CONTROL

Company, manufacturer, or type of industry	Period	Average annual net investment	Average annual profit	Percentage of profit to investment
Musical instruments	1913	$9,557,242	$779,415	8.14
Brewery	1912	2,392,010	156,745	6.55
Office devices	3 years to 1913	11,646,224	1,789,433	15.37
Small brewery	1913	376,125	61,865	16.44
Textiles	3 years to 1913	151,018	46,315	30.67
Photographic supplies	1913	525,078	88,973	16.94
Rubber goods	3 years to 1913	1,368,722	161,485	11.80
Drugs	3 years to 1913	288,031	33,161	11.51
Motion pictures	3½ years to 1913	677,404	293,354	43.30
Fertilizers	3 years to 1913	5,112,926	385,415	7.54
Leather goods	3 years to 1913	2,390,725	341,126	14.27
Musical instruments	2 years to 1913	10,909,986	3,740,196	34.30

Company, manufacturer, or type of industry	Period	Average annual net investment	Average annual profit	Percentage of profit to investment
Textiles	1913	3,607,648	1,204,921	33.40
Textile machinery	1913	1,410,840	62,106	4.40
Hair (taken from hides, skins, etc.)	½ year to 1913	97,044	21,378	44.06
Textile machinery	1913	1,560,704	21,390	1.37
Cotton goods	1913	1,716,176	123,870	7.22
Steel	1913	2,238,109	538,874	24.08
Cement	1913	1,392,216	115,141	8.27
Paper	1913	1,099,212	42,715	3.89
Textile machinery	1913	371,122	57,036	15.37
Refrigerating apparatus	1913	3,010,087	330,735	10.99
Tinware, aluminum, etc.	1913	1,438,225	131,332	9.13
Tinware, aluminum, etc.	1913	490,597	48,522	9.89
Iron and steel	1913	3,799,603	225,115	5.92
Manufacturing stationery	1913	11,452,084	594,390	5.18
Grinding and crushing machinery	1913	2,928,370	262,605	8.97
Wire	1913	950,821	116,705	12.27
Brass	1913	22,131,599	1,917,605	8.66
Chemicals	1913	337,794	78,919	23.36
Carpet	1913	1,726,558	229,941	13.31
Rubber goods	1913	248,129	53,279	21.47
Rubber goods	1913	658,896	108,027	16.39
Electric lighting fixtures	1913	95,395	69,680	73.04
Automobile specialties	1913	460,458	516,138	112.09
Steel chains	1913	304,271	17,045	5.60

Cost of Establishing a Business. The cost of establishing or building up a business is a cost item that not infrequently exceeds the full first cost of an expensive plant, and rarely is less than 20% of the first cost of a manufacturing or public utility plant plus the depreciation accrued but not yet paid. Aside from the costs of advertising for and soliciting new business, there are the cost of training new employees besides the accumulated deficit in fair return on the investment. All these development costs, as we term them, may be calculated very readily if three annual items are known from the time of the initial investment down to the time that deficits in fair return cease.

It is customary to class the interest on the investment during the period of plant construction as an item by itself, called "interest during construction," but it might with perfect propriety be included as a part of the development cost.

Intangible cost is the cost involved in attaching business to a plant.

Intangible value is that part of the total value (deduced by capitalizing prospective net earnings) remaining after deducting the tangible or physical value from the total.

Intangible cost is given various names, such as "development cost," "development expense," "going cost," "going value," "going concern value," "cost of establishing the business," etc.

Intangible value is also given various names, such as "franchise value," "going concern value" (occasionally abbreviated to "going value"), "good will," etc.

Since some terms like "going concern value" are used by some people to mean intangible *cost,* whereas other people use the same terms to mean intangible *value,* no end of confusion and illogical reasoning results.

"The franchise value" of a public utility corresponds to the "good will" of a business that is not operated under a franchise, for both are dependent on prospective net earnings. There is, however, such a thing as "franchise cost," which is the cost of securing a franchise. This has no necessary relation to the value of the franchise.

There are two commonly used methods of estimating going or development cost: (1) The deficit method as applied to the actual plant investment, income and expenses; (2) the deficit method as applied to a hypothetical projected new plant, the construction of which is supposed to start at the time of the appraisal and its customers subsequently attached until its net revenue equals that of the existing plant, but without competing with the existing plant. The first of these methods is often called the historical or Wisconsin method. The second is often called the Alvord method.

We now propose a third deficit method, which resembles the Alvord method except in that it is assumed that the new hypothetical plant must compete with the existing plant.

Each of these three deficit methods makes the going or development cost a sequel to "interest during construction," for the deficit is the deficiency in a fair interest return on the investment. Each method compounds the interest on the deficit. The interest rate used is a "fair return rate."

It will be seen that the historical or Wisconsin method of deriving the development or going cost logically associates this cost with the actual cost of the physical plant and not with the estimated cost of reproducing it under present conditions. The Alvord method, however, was devised to secure a development cost that could logically be associated with the cost of reproduction of plant under recent past and immediately prospective conditions. However, we think it falls short of accomplishing this end, and for that reason have proposed the third method.

The advocates of appraising the cost of reproducing the physical plant under recent past or prospective conditions, and of assigning a functional as well as a natural depreciation, have apparently not realized that in essence they were proposing to set up an *alternative* plant as a criterion by which to judge the value of the existing plant. But even if they have clearly seen this implication they have not seen its corollary, to wit: If a new *alternative plant* is set up as a criterion of the worth of the existing old plant, then a new *alternative business* must also be estimated to attach to the new alternative plant. But a new alternative business can be secured only by *competing* with the old existing plant.

To establish business under such a competitive condition will cost far more than under the Alvord theory, and that the Alvord method therefore gives an irreducible minimum, if present and prospective conditions are assumed. But we object to the claim

TABLE II. DEVELOPMENT COST BY THE ALVORD METHOD

Year	Old plant Gross revenue	Old plant Operating expense	Old plant Net earnings	New plant Gross revenue	New plant Operating expense	New plant Net earnings	Total difference	Present worth factor (6%)	Net difference
1914	$24,000	$14,000 2,200*	$ 7,800	.....	$ 6,000	—$ 6,000	$13,800 2,700†		
		$16,200					$11,100	$0.9434	$10,470
1915	26,800	14,400	12,400	$12,000	10,000	2,000	10,400	0.8900	9,260
1916	28,100	14,600	13,500	20,600	12,400	8,200	5,300	0.8396	4,450
1917	29,500	14,800	14,700	26,500	13,900	12,600	2,100	0.7921	1,660
1918	30,900	14,900	16,000	30,000	14,700	15,300	700	0.7473	520
1919	32,200	15,000	16,200	32,200	15,000	16,200	.....	0.7050	.....
Development cost									$26,360

* Depreciation differential. †Interest during construction previously allowed under reproduction of physical plant.

that the Alvord method is wholly consistent with the "cost of reproduction method." An alternative plant spells competition, and therefore a business built up under competition and not under the ideal condition assumed in the Alvord method.

Street railways, electric interurbans, steam railways, telephone lines and even water works have been built to compete with existing plants. They have in nearly every case encountered very great development cost, often so great as to make the new properties dismal failures. This is strikingly seen in the so-called "independent telephone companies," whose development cost has usually been ruinous to them. Such alternative plants may have been built because their promoters assumed that lower plant costs could be had than were actually incurred by the old Bell plants. But the promoters failed to estimate their probable development or going cost under competitive conditions. Could an assumption of the Alvord method conditions have been realized in practice the consequent low development cost might have justified the building of "independent telephone" systems. But practice and theory failed to meet there, as they fail to meet anywhere when it is assumed that a new alternative plant can be built to serve a community habituated to use the existing old plant, yet without engaging in a competitive fight for business with the existing plant. In other words, while we can conceive the ideal conditions of the Alvord method, and while we grant that those conditions yield a low development or going cost we refuse to admit that the Alvord method is fully concordant with any reproduction method of estimating the cost of physical properties.

Alvord Method. For a complete discussion of this method of estimating development cost the reader is referred to a paper read before the American Society of Civil Engineers by Metcalf and Alvord entitled "The Going Value of Water Works." The paper was reprinted in Engineering and Contracting, March 29, 1911.

In Table II we give a recent application of this method to a water works that served about 8,000 people in the year 1914. The investment in the plant alone was about $100,000 exclusive of overhead costs. Its gross revenue and operating expense for 1914 are given in the table as $24,000 and $14,000 respectively, and after deducting an estimated depreciation correction for that year the net earnings were $7,800. Construction of the hypothetical new plant was assumed to begin and end in 1914, and result in a $6,000 operating expense (organization of staff, soliciting business, etc.), with no income from operation.

The business of the old plant was assumed to continue its previous rate of growth for five years, and that of the hypothetical plant was assumed to overtake that of the old plant in 1919. The eighth column, "Total Difference," is found by subtracting the net earnings of the new plant from those of the old plant. The items in the eighth column are multiplied by the "present worth factor" in the ninth column to get the "net difference" in the tenth column — that is, the present amount (in 1914) of the difference in

net earnings between the old and the new plants. The "present worth factor" is taken from a compound interest table, such as that on page 12 of Gillette's "Handbook of Cost Data." The development cost by the Alvord method is thus calculated to be $26,360 in this case. This $26,360 was added to *depreciated* value of the old plant.

Wisconsin Method. Applying the Wisconsin method to this same water works, as far back as the accounting records were available, and the result is shown in Table III. The original nucleus of the

TABLE III. PLANT INVESTMENT AND EARNINGS

Year	Plant, Jan. 1	Gross earnings	Apparent expenses	Apparent net earnings
1900	$ 76,200	$13,000	$9,500	$3,500
1901	77,200	13,800	10,700	3,100
1902	77,900	13,500	10,000	3,500
1903	79,100	14,200	9,800	4,400
1904	81,500	15,200	10,400	4,800
1905	82,800	15,700	10,000	5,700
1906	85,300	17,600	12,100	5,500
1907	87,200	18,300	15,100	3,200
1908	88,300	18,400	14,400	4,000
1909	91,300	19,900	15,000	4,900
1910	93,500	20,700	13,900	6,800
1911	96,800	21,800	14,900	6,900
1912	98,300	22,400	16,100	6,300
1913	99,000	23,900	14,500	9,400
1914	100,000	24,000	14,000	10,000
Total	$1,314,400	.....	.....	$82,000

plant was built in 1885, but it had passed through a receivership and no accounting records back of 1900 were available. In such a case it might at first appear impracticable to apply the Wisconsin method, but it is possible to approximate quite closely to the development cost incurred during the period for which the annual earnings and operating expenses are available. Thus the reproduction new cost of the plant, less overhead charges and land values, was about $100,000 as of Jan. 1, 1914. Overhead charges were eliminated, for those that had been charged did not appear in the ledger plant account, but in operating expense. The second column in Table III was arrived at by deducting successively the yearly additions to plant, recorded in the ledgers, starting with $100,000 as the base in 1914. Thus it was established that the plant investment was $76,200 as that of Jan. 1, 1900. The gross earnings and operating expenses (in round numbers) were set up in columns 3 and 4, from which the "apparent net earnings" in column 5 were deduced. The "apparent expense" includes taxes and current maintenance but includes no depreciation fund annuity.

Table IV starts with the $76,200 property investment derived from Table III and column 4 of Table IV is the same as column 5 of Table III. An 8% "fair return rate" was assumed, and $76,200 multiplied by 8% gave $6,100 (in round numbers), which was entered in column 3, Table IV. Since the net earnings were only $3,500, there was a deficit of $2,600 below the fair return of

TABLE IV. DEVELOPMENT COST BY THE WISCONSIN METHOD

Year	Property Jan. 1	8% fair return	Apparent net earnings	Deficit	Plant additions
1900	$ 76,200	$ 6,100	$ 3,500	$2,600	$1,000
1901	79,800	6,400	3,100	3,300	700
1902	83,800	6,700	3,500	3,200	1,200
1903	88,200	7,060	4,400	2,660	2,300
1904	93,160	7,450	4,800	2,650	1,300
1905	97,110	7,770	5,700	2,070	2,500
1906	101,680	8,130	5,500	2,630	1,900
1907	106,210	8,500	3,200	5,300	1,100
1908	112,610	9,010	4,000	5,010	3,000
1909	120,620	9,650	4,900	4,750	2,200
1910	127,570	10,200	6,800	3,400	3,300
1911	134,270	10,750	6,900	3,850	1,500
1912	139,620	11,170	6,300	4,870	700
1913	145,190	11,610	9,400	2,210	1,000
1914	148,400	11,870	10,000	1,870	....

Development cost including overhead charges on the $23,000 additions to plant from year 1900 to 1914 ....$50,370

$6,100, so this deficit was entered in column 5. During 1914 plant additions of $1,000 were made, as shown in the sixth column. Hence if we add this $1,000 and the deficit of $2,600 to the $76,200 we have a total property cost of $79,800 as of Dec. 31, 1900, or as of Jan. 1, 1901. Accordingly this $79,800 is entered in the second column opposite 1901, and the same sort of calculations is made for 1901 as for 1900. Thus the table is built up, resulting in a development cost of $50,370 for this plant during the 15-year period. How much more it was prior thereto no one knew, but it was scarcely worth inquiring into in this case, for here already was a development cost equal to nearly half the physical cost. It is true that this $50,370 includes those overhead costs (on the $23,000 of plant additions) which were improperly charged to operating expense from 1900 to 1914. But this may be readily estimated and deducted. The most important thing to note is that the development cost thus deduced should be added to the cost *new* of the physical plant and not to its *depreciated* value. The reason for this is that the operating expenses include no depreciation annuity, hence no provision for the accrued depreciation existing in the old plant. Were an adequate depreciation annuity included in operating expenses each year from the time the plant was built down to date, it should be at least sufficient to build up a depreciation fund equal to the accrued depreciation. And were this done the development cost would be increased by exactly the amount of the depreciation fund. Had that been done, then the resulting development cost would be properly added to the depreciated value of the plant to get the total investment in "tangible" and "intangible" property.

An article on "Development Cost" in Engineering and Contracting, June 26, 1912, gives a long reprint of one of Gillette's appraisal reports on an electric utility in which are outlined many of the details to be considered in applying the Wisconsin method.

These details were worked out prior to the decision of the Wisconsin Railroad Commission (Hill vs. Antigo Water Co., 3 W. R. C. R. 623), in which they first adopted what is now styled the Wisconsin method of determining "going value." But prior to that other engineers had suggested and applied the same method. In fact this deficit method is prescribed in a contract between the city of New York and the Empire City Subway Company dated May 15, 1891, from which we quote:

"The said party of the second part shall, at any time after Jan. 1, 1897, upon demand of the commissioners of the Sinking Fund in the City of New York . . . sell, assign, transfer, convey and set over to the Mayor, Aldermen and commonality of said city the subways, conduits and ducts constructed by it, as aforesaid, . . . and other property . . . upon payment of the actual cost thereof; and if the said company shall not have earned 10% per annum on actual cost during the terms of this contract a further payment shall be made in addition to the cost not exceeding 10% on such cost to the extent of such deficiency in annual earnings, or such less sum as may be agreed upon."

Doubtless older contracts of this nature exist.

Below we quote from a decision of the Federal Court rendered in 1904, in which the Wisconsin method was repudiated by the court five years before it was adopted in Wisconsin. It is interesting to note the false reasoning used by the court in repudiating the deficit method. The court says:

"The company may have purchased a plant larger and more expensive than necessary; the current rates of interest may have been abnormally high; many causes which have absolutely no relation to the *value* (typographical emphasis ours) of the company's business now as a going concern may have increased or diminished the deficiency in revenue. [165 Fed. 657 (C. C. W. D., Cal., 1904).]"

Note how the court slips from a discussion of cost into a discussion of value. A deficit in fair return is a *cost,* and it not only may not but actually does not have any necessary relation to the *value,* for the latter depends entirely on capitalized prospective not earnings. The court falsely sets up a criterion of value as a way of discrediting an actual cost, yet the court does not thereupon conclude to adopt value (capitalized net earnings) as the appraisal base. This sort of sophistry is met on every hand. Attorneys frequently attempt to discredit a given *cost* by showing that it has no commensurate *value.* Yet they repudiate entirely the use of value (capitalized net earnings) as a rate-making base. In such cases if the appraiser has a clear conception of the distinction between cost and value, no great difficulty is found in making the distinction clear to the commission or court. Both "going cost" and "franchise value" should be presented for consideration, but they should be kept entirely distinct.

Separate Plant Theory of Prorating Joint Costs. Where a plant is used to produce only one class and size of units no question arises as to prorating joint costs, for then the total cost during a

given period of time divided by the total number of units produced in that time gives the true and full unit cost, assuming that the depreciation costs, lost time, etc., have been properly equated. But where a plant produces units of different classes or sizes the questions of prorating the joint costs often becomes vitally important.

The history of industry furnishes many examples of crippled business, attributable largely to improper methods of prorating joint costs. If one of the joint products is priced at less than is equitable, while another product is priced at more than is equitable, the resulting large demand for the underpriced product may speedily pile up losses, while at the same time the decreased demand for the overpriced product may cut down the profitable sales to a vanishing point.

Another source of loss from inequitable prorating of joint costs is to be found where a " side line " of products is improperly loaded with cost charges and made to appear to be unprofitable. Thus many a " side line " is stifled before it has had a chance to become more than a " side line."

Before a rational theory of prorating joint costs can be developed, the prime objects of cost keeping and cost analysis must be considered. Correct unit costs are desirable for two purposes: (1) To furnish a basis for fixing equitable and profitable unit prices; and (2) to provide acurate criteria by which to judge the economic efficiency of men, machines and methods. Both these objects are attained when joint costs are so prorated that the resulting unit costs may be compared with similar unit costs incurred where no prorating is necessary. Thus a merchant who deals in many kinds of goods should so prorate the joint costs — rent, insurance, delivery, clerical, management, etc.— that he may compare the unit cost of any class of goods with the unit price charged by a competitor who specializes in that particular class of goods. For example, the unit cost of candy sold by a department store should be comparable with the unit price of candy charged by a candy store, or, better still, with the unit cost of candy in a candy store.

If a prorating theory is such as to prevent equitable comparison of unit costs of joint production with unit costs of separate production, then the economic efficiency of joint production can not be gaged by comparison with separate production. Furthermore, equitable unit prices that will attract business and secure adequate profit can not readily be made unless the unit costs of joint production are strictly comparable with those of separate production.

If this is a sound economic premise, it follows that a rational method of prorating joint costs must be one that is based on costs incurred under the most economic production of each class of units by a separate plant for each class.

In this connection it is well to note the significance of the fact that joint costs can not be prorated at all where separate production of each of the units is not possible. Thus, the total joint cost of all the parts of a beef may be known, but the unit cost of each of its various marketable parts — sirloin, chuck, liver, etc.— can not

be determined. If under such a condition joint costs can not be prorated, it follows that the one condition precedent to prorating joint costs is the ability to secure unit costs of each class of units where no other class of units is produced.

We thus come to this important generalization as to prorating joint costs:

Where several classes of units are produced jointly, the total costs of joint production must be prorated among the several classes in proportion to the cost of producing each class (or its equivalent) by a separate plant designed solely for the economic production of the given number of units of that class.

For convenience of reference let us term this rule the separate plant theory of prorating joint costs, or, briefly, the separate plant theory. When the by-product cost theory — which will be considered later — is not involved, this separate plant theory is applicable under all conditions, and the application of it will disclose both the true economic efficiency of production and the equitable unit price of each class of products jointly produced.

Joint production of different classes of products is an economic mistake unless the total resulting cost is less than the sum of the costs of producing the products separately or in joint groups of fewer different classes. The saving effected by joint production is to be allocated to the different classes of products. The separate plant theory allocates this saving in proportion to the costs of separate productions. Were two independent manufacturers of different products intending to join forces, and were these manufacturers making the same percentage of profit on the cost of their products, it is evident that each would regard it as fair to accept his share of the increased profit resulting from the consolidation in proportion to his total original cost of production.

Similarly if a company whose sole business was furnishing electric power to a street railway were to consolidate with a company whose sole business was furnishing electricity for street lighting, the resulting saving in the cost of generating current in a joint power plant would be equitably allotted to each company in proportion to its independent cost of generating current, the only proviso being that each company had an economic generating plant. Since, under such conditions, the investment in each of the two separate generating plants would be roughly proportional to their respective peak loads, it follows that an approximation to the separate plant theory is had when the first cost of a joint generating plant is prorated to the different classes of electric service in proportion to the separate peak load of each class. The peak load theory of prorating investment is therefore justifiable only when it conforms in its results rather closely to the results obtained by application of the separate plant theory.

While generating plant investment is a function of peak loads, fuel expense is a function of the amount of current generated, as well as of certain other factors such as the shape of the load curve. But all these varying factors are given their proper recognition

in prorating joint fuel expense when the separate plant theory is applied. Likewise every other operating expense is properly prorated on the separate plant theory. When this fact is clearly perceived, a key is had to the solution of all the troublesome prorating problems that confront the person who is trying to ascertain what are equitable rates of charge for electricity or other public utility service furnished to different classes of customers. Indeed the separate plant theory, when fully understood, leads to a proper recognition of the various competitive conditions that are so apt to break down any system of rates of charge based on the ordinary methods of cost analysis.

Turning back to the rule for prorating, above given, it will be seen that the separate plant need not produce precisely the same sort and number of units, provided it produces their equivalent. By this we mean the competitive equivalent or substitute service. To illustrate, assume the existence of a steam railway paralleling a navigable river and handling a heavy freight traffic, but a light passenger traffic. If it were not for the freight traffic an electric trolley line would handle the passenger traffic most economically. Were it not for the passenger traffic, the freight would be most economically hauled in barges. But, by virtue of the combined traffic, the steam railway is more economic than a separate trolley line and a separate barge line. The total annual joint costs of the steam railway are properly prorated to the two classes of traffic — freight and passenger — in proportion to the annual costs by the most economic separate plants, namely, a barge line and a trolley line. The barge line would not give precisely the same sort of service as the steam rail service, but it would give its equivalent — an economic substitute service.

One paragraph of digression may perhaps be pardoned. The efforts of railways to eliminate water competition have caused many unfavorable comments, resulting finally in legislation to prohibit such "iniquitous throttling of free competition." Yet a better understanding of the principles of economies may fully justify the elimination of water borne traffic in many places. Certainly if one railway line can handle the combined traffic at a lower cost than the sum of the costs with separate railway and boat lines, it is economic to eliminate water traffic. But when such elimination is effected, equitable rates of charge are to be determined by application of the separate plant theory.

Average Cost Fallacies. Unless the separate plant theory, or some approximation to it, is applied in cost analysis, so-called "average unit costs" are often calculated and used in price making. Yet the "average" may be improperly applied in price making. Thus, the average cost of generating electric current in a central station may be 1 ct. per kw.-hr., where the average station load factor is, say, 40%. But to use this 1 ct. cost as a basis for charging residence lighting customers would be economically wrong, even were there no distribution and service costs. Residence customers causing a station load factor of 15%, business customers 22%, and large power customers 60%, may so amalgamate as to cause an

average of 40% station load factor; but, as none of the three classes would alone cause a 40% average, none should equitably be charged on the basis of the average 1 ct. generating cost.

While the electrical engineers and managers recognize the importance of such a distinction, the general public often does not. Even keen business men are frequently so ignorant of the principles of correct prorating of costs that they are easily misled by such sophistical arguments as this: "Small shippers of freight are charged the same car load rates as are large shippers. Hence small users of electric current should be charged the same rate as large users — a rate based on the average cost and therefore not discriminatory."

The average cost sophistry is often best exposed by insisting upon the application of average cost to individual cases only where the individual case corresponds with the same average economic conditions.

It has been seriously proposed to estimate all rates of charge for railway freight service of a given class by application of a rule like this: To a fixed cost of blank cts. per ton add blank cts. per ton-mile.

In estimating the cost of hauling uniform loads by wagon, such a rule is applicable, provided all conditions are the same as those upon which the cost rule is based. But in hauling miscellaneous freight with a railway plant, the prorating of fixed costs upon any general average theory leads to economically absurd results. In a given railway it might be concluded that if the total costs not affected by the length of haul were divided by the total tons of freight, there would be an average cost of, say, $1 per ton. Then the cost of moving the freight might be ¼ ct. per ton-mile. If rates were based on such an application of averages in allocating total costs, this absurd result would occur: That it would be cheaper to haul freight 10 miles by wagons than by rail. Now, as a matter of fact, precisely that sort of economic absurdity is actually to be found not only in freight rates but in the prices charged for all sorts of products and services. When traced to the cause, the cause will usually be found to be improper prorating of joint costs and the use of so-called "average costs" as a basis for pricing.

Fallacies in Prorating Proportionally to Direct Costs. Almost as prolific in error as the "average cost theory" is the theory of prorating all joint costs in proportion to direct costs. Yet all books on accountancy concur in recommending this method of prorating. There are, it is true, certain joint or indirect elements of cost that are almost direct functions of certain direct cost. Thus the general foreman in charge of several gangs doing different kinds of work is likely to give each gang an amount of his time proportional to the number of men in each gang. So, too, shop rent is closely related to the number of workmen in certain cases, and therefore is properly prorated to the direct cost of labor where wages are relatively uniform. But there are endless conditions under which joint costs are not direct functions of direct costs. Indeed certain

joint costs, notably plant interest, may increase as the direct costs decrease. For example, where power is generated hydro-electrically the direct labor costs grow relatively smaller as the investment in the power plant increases. How irrational, then, it is to apportion interest and depreciation charges in proportion to the cost of direct labor in such a plant.

Estimating Direct Costs by Approximation. Direct costs are those directly assignably to a unit or group of similar units of product. If it were possibie to keep a record of the time spent by each workman on each class of units, no prorating of labor costs would be necessary except as to the cost of idle or lost time. It is often impracticable to keep continuous time records of each class of work done by each workman. In such cases some simple method of prorating the labor cost is used, and the common mistake is to use too simple a method — one that secures simplicity at the expense of accuracy. Thus joint labor is frequently prorated in proportion to the number of units of material handled, shaped or placed by the laborers.

Prorating labor according to the units of material is often an excellent plan if judiciously carried out. It should involve periodic timing of all the labor processes in relation to the units of material treated by each process. Thus, by minute-hand timing of, say, 5 or 10% of the labor time each month, it is often possible to allocate correctly the entire labor of the month by ascribing certain labor costs to each different class of units of material handled under given conditions. But serious errors may arise if the timing is not carefully done and at regular intervals not too far apart.

Even where the units of material handled are not counted the method of timing labor processes periodically is often an excellent method of approximating the amount of direct labor on each process. The periodic-timing method is so inexpensive that it is remarkable how seldom it is applied as a means of approximating direct labor costs.

Where workmen use machines the direct cost both of the labor and the machines is ascertainable in the manner just indicated. In cases where a rather expensive machine is used, it will usually pay to record the length of time the machine is used for each process. Then the direct cost of the machine is readily assignable to each process and only its idle time remains to be prorated. This method is far preferable to prorating machine costs in proportion to direct labor, unless the same labor cost occurs per unit of time in every case that the given machine is used.

Real estate rental can usually be quite accurately prorated according to the floor area assigned to each machine, or to each workman, or to each process. The cost of heat and light is similarly apportionable.

The cost of accounting is usually quite closely related to the number of entries made. Hence by counting the number of entries that each account averages per month, a very close approximation to the direct cost of accounting can be secured.

Once the importance of approximating the direct cost of each

process or product is appreciated, comparatively simple yet effective methods of approximation will be devised. By doing so the remaining amount of joint costs will be materially reduced, and thus render any errors of prorating less serious.

Prorating Non-Productive Time. Since neither machines nor workmen are usually worked continuously to full capacity, it often becomes important to determine the cost of non-productive time and to prorate that cost equitably.

Non-productive time is to be allocated in proportion to productive time, but it is usually desirable to record the resulting unit cost of non-productive time separately from the cost of productive time. By doing so attention is focused upon the cost of lost time, and this generally leads to greater effort to increase the "load factor." Furthermore, one of the main causes of wide fluctuations in unit costs from week to week or year to year is the variation in the percentage of idle time. Hence unless the idle time cost is shown separately, there can be no satisfactory comparison of unit costs at different periods.

In case the by-product theory of cost keeping is to be applied, the cost of idle time is not prorated to the by-products.

By-Product Theory. Hitherto we have considered costs under what may be termed the full cost theory. In order to increase total profits under competitive conditions, it is often necessary to assess against certain by-products only the additional costs of producing them. But a philosophical analysis of the reason for doing so brings us back to our separate plant theory in its broadest form; for if a by-product can not normally be sold at a price in excess of the added cost of producing it with a given plant, then some other separate plant must be producing that class of product at a lower cost than the market price.

Prorating According to Sales. The prorating of joint costs in proportion to the sales of each class of product is at first sight wholly irrational, for it would seem that this is placing effect before cause. Nevertheless this method of prorating is not wholly irrational, and in some cases it is preferable to other methods because it may be a simple way of approximating the separate plant method of prorating. Obviously if a product is sold in a competitive market, the fact indicates that the average unit price over a long period is sufficient to yield a fair profit to some one of the competitors, if not to all of them. Since the competitor who is able to fix the price of a product often is equipped with a plant especially designed to make that product and no other, it follows that other plants that produce the same product plus several other products, are thus automatically forced to adopt the separate plant theory of prorating their joint costs.

Conclusion. The subject under discussion is susceptible of such a diversity of treatment and has so many ramifications that we have been able to touch "the high places" only in this article. We shall have accomplished our object, however, if we have made it clear that one general, underlying theory — the separate plant theory — is applicable in every case, and that all other tenable

theories of prorating joint costs are short-cut approximations to the general theory.

When Is It Profitable to Retire an Old Plant Unit? Business success often depends largely on the judgment used in scrapping a comparatively new plant to make way for a newer one. British manufacturers have been proverbially slow in retiring old machinery, whereas Americans have more often gone to the other extreme.

The problem has been put to a score of engineers, to several skilled accountants, and to a few business men, not one of whom gave a completely correct solution. It was submitted also to a well known business correspondence school, which likewise failed to give a correct answer. That school in turn passed the problem on to an expert accountant and to a well advertised "efficiency engineer," both of whom gave erroneous replies. It may be assumed, therefore, that the problem is of a sort whose seeming simplicity is itself a cause of hasty reasoning where deliberate and painstaking study is actually required.

This is a case where it will not suffice to give an answer in general terms without explaining in detail the precise quantitative meaning of every economic term. Thus, one general rule that was submitted was this:

Retire any old plant when the annual profit will be increased by substituting a more economic plant.

This is correct as far as it goes, but it is completely correct only when the term "profit" is fully defined. Since profit depends on cost, a definition of cost must be given, even to every element that enters into cost. As will be shown later, the cost elements are numerous and several of them are not understood even approximately by most men.

Professor Taussig, of Harvard, gives a general rule in his "Economics," Vol. II, p. 85, as follows:

"It will be profitable to tear down an old or ill-adapted building and replace it with a new building only when the new one promises to yield not only enough to pay a satisfactory return on its own cost, but in addition enough to compensate for the loss of net revenue which the old one still yielded."

Here the ambiguous terms are "a satisfactory return" and "net revenue," both of which require no small amount of explanation. Professor Taussig's rule borders dangerously close to an error that is most commonly made in attempts to solve this problem. It is quite generally believed that a new plant can not economically replace an old plant unless the net earnings that the new plant yields are sufficient to pay interest charges on the original cost of the old plant as well as on the first cost of the new plant. Yet this rule is entirely false, no matter what the definition of net earnings may be.

A correct solution of this problem was given by Gillette in Engineering and Contracting July 14, 1915, but, as it was somewhat buried in an article entitled "A Rational Method of Calculating Depreciated Value" (see Chapter II), it seems wise to

outline a solution of the problem here and to discuss more fully the reasoning upon which it rests.

As between two plant units the choice obviously falls upon the one that yields the greater profit over a term of years. But when one of the two plant units is already owned and in service, while the other must be purchased new, it is not obvious at once that in calculating the cost of the product, the original cost of the old plant unit has nothing whatever to do with the case. This is the first logical pitfall. The second pitfall is encountered when the element of depreciation is reached, for it has never been perceived that, in order to solve the problem correctly, natural depreciation must be entirely separated from functional depreciation and that the latter must be treated precisely as if it were an item of insurance. Natural depreciation is the loss of value due to the action of the forces of nature; whereas functional depreciation is due to invention, growth of business that renders a plant inadequate, and other social forces. In calculating the annual cost, natural depreciation should be classed with repairs, for that is what it is in essence. But on the other hand, a functional depreciation annuity should be classed with a fire insurance premium — an element to be provided for by an annuity based on past experience covering many instances. This distinction is vital. Having ascertained from a study of the history of many plant units of the same general class what the average functional life of the given plant unit may be expected to be, it is a simple mathematical matter to determine what percentage should annually be allowed as the functional depreciation rate (F).

For any given new plant unit, we may express the annual profit derivable from it, thus:

$$P = G - K \qquad (7)$$

P = annual profit.
G = annual gross income.
K = annual cost.

If we use capital letters for the new plant unit and lower case (small) letters for the old plant unit, we have for an old plant unit:

$$p = g - k \qquad (8)$$

If the new plant unit and the old one are equally profitable:

$$P = p, \text{ or} \qquad (9)$$
$$G - K = g - k \qquad (10)$$

If, as is ordinarily the case, the gross income is not altered by substituting a new plant unit for an old one, then G = g, and:

$$K = k \qquad (11)$$

Let

E = Annual operating expenses (including repairs and taxes) equated during the estimated economic life of the new unit.
e = Ditto for the old plant unit during its remaining economic life.
C = First cost of new plant unit.
S = Salvage value of new plant unit.
s = Ditto of old plant unit.

r = Interest rate, including any risk insurance not covered by F or elsewhere.
F = Functional depreciation rate (not including depreciation from natural causes, such as wear and tear, rot, etc., which are covered by "repairs").

Then

$$K = E + (C - S) F + r C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Only a little study is needed to make the truth of Equation (12) evident; but much more study is ordinarily required to make it evident that Equation (13) is equally true.

$$k = e + r s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

To almost every one it has seemed essential that the equation of annual cost for an old plant unit should contain the same number and kinds of terms as for a new plant unit. Here it is that the reasoning process must be carefully scrutinized. Why does the term $(c - s)F$ vanish in Equation 13? Because $c = s$. Why so? Because the condition that is tacitly assumed when $K = k$ is that the old plant unit has depreciated and can therefore be purchased at a depreciated value (c), which value (c) can be no greater than its salvage value (s) if the time to retire the old plant unit has arrived.

A more elegant, but more elaborate, process of reaching the same conclusion is given in Chapter II. There are several other ways of indicating the correctness of the above reasoning as to Equation 13.

Suppose, for example, the choice between a new and an old second-hand machine were in question, and that each could be bought in a market. Suppose the market price of the old machine were little above its scrap value. Then it would be perfectly clear that Equation 13 would give the annual cost of production with the old machine.

Suppose, as another example, that an old machine is owned but that it had been purchased several years ago as a small part of a large second-hand plant, and that the price paid for it is unknown. Would it be rational to insert in Equation 13 a factor c representing its cost to the original owner, even if it were ascertainable? Assuredly not, for that would not be the cost to the present owner, nor would it be any more helpful to attempt to estimate (by prorating) its cost to the present owner when the machine was newer than it now is; particularly if the present owner had paid altogether too much for the entire plant.

Suppose, as a third example, that the present owner of a plant has received it as a gift or as an inheritance, and that therefore the cost of the old plant unit to him has been nil. Should c then be made o? Clearly not, for the owner is not concerned with the original cost to him, which is in this case nothing, but with its present cost of replacement, or its true market value. This, under the assumed condition of expired economic life of the old machine, is its salvage value (s).

Since $K = k$, we have:

$$E + (C - S) F + r C = e + r s \quad \text{.................. (14)}$$

This is the equation of condition by which to judge whether an old plant unit has just reached the age of retirement, assuming the gross-income from both new and old plant units to be identical. When the gross-incomes are not identical, the method to be pursued is now self-evident. When the new plant unit is economically superior to the old, there results an inequality:

$$E + (C - S) F + r C < e + r s \quad \text{.................. (15)}$$

Now a few words as to F. This factor, namely, the annual rate of functional depreciation, is perhaps the factor most likely to puzzle those who have not studied the different kinds of depreciation and their economic significance. Functional depreciation is the loss of value due to obsolescence and economic inadequacy. Average functional life is the term of years that a plant unit of the given class remains in use before it is superseded by an improved or larger unit. The functional depreciation rate is the annuity rate which compounded at the interest rate (r) will yield an amount equal to unity at the end of the average functional life.

Another expression requiring explanation is "equated annual expense." As here used, to equate means to secure an economic average by a sinking fund method of calculation. To equate annual repairs, for example, calculate the total cost of repairs of the first year at compound interest up to the end of the last year of economic life of the given plant unit. Calculate similarly the total cost of repairs of the second year, the third year, etc., up to the end of the last year of economic life. Add all these compounded repair costs together and multiply by the annual deposit in a sinking fund which if started at the beginning of the life will redeem $1 at the end of the economic life of the given plant unit. The product is the equated annual cost of repairs. Of course if repair expenditures are uniform, they automatically equate themselves, but this is rarely the case.

Since it is commonly believed that a new plant unit must show an increased profit sufficient to pay interest on the original cost of the old plant unit that it displaces, it is well to point out the fallacy. This is a fallacy of confusion of a general class of improvements with a particular improvement. Progress costs money. Functional depreciation is a loss of value due to progress. Hence it is the cost of progress. But progress implies increasing profit, which must be at least sufficient to equal the functional depreciation. In other words, the profit from progress in general must pay for the cost of progress in general.

Now comes the curious mental twist by which this truth is distorted into an error, thus: The profit from each individual instance of progress must pay for the cost of that particular instance of progress. Whence naturally follows the blunder in the final conclusion that every new plant unit must be sufficiently effi-

cient to pay not only its own individual interest charges but those on the original cost of the plant unit that it displaces. As previously pointed out, a functional depreciation annuity is precisely like a fire insurance premium. Each is based on the law of averages for a given class of risks. It would be evidently illogical to refuse to erect a new factory building to replace one that had burned, unless the new one would yield an increased profit sufficient to pay interest both on its own cost and on the value of its predecessor. Equally illogical is the reasoning that would make an improved machine bear the interest burden of its obsolete predecessor.

These examples of false reasoning should serve to indicate the necessity of studying the general processes of reasoning in a systematic manner. Nearly every trained engineer can juggle equations with skill and accuracy, but such ability is no evidence of equal ability in the reasoning that should precede the setting up of an equation that correctly and completely embodies all conditions, implied or connoted as well as explicitly stated.

The Calculation of Rates for Electric Current. The following is an abstract of a report to the Oro Electric Company relative to a schedule of electric rates for a proposed hydroelectric plant in California.

The method of attacking this problem is of general applicability in all electric rate problems where it is desired to base the rates to each class of customer on the cost of serving that class. It is not to be inferred, however, that each rate should necessarily be based on cost. But it is usually desirable and often necessary to determine the relation of rates to costs, and for this purpose the following method of solving the problem will be found helpful.

Definitions. There is as yet no unanimity as to the meaning of terms used by appraisal and rate making engineers. For the purpose of this discussion the following definitions will apply. The definitions are arranged alphabetically.

Active Load. The maximum load in kw. recorded on a customer's demand meter of the Wright type.

Apparent Diversity Factor. The quotient found by dividing the total connected load by the station peak load. See *Diversity Factor.*

Additional Cost Rate. A rate based not on the full cost of the service including fixed charges, etc., but upon the additional cost of furnishing the additional service. See *Full Cost Rate.*

Capacity Cost. See *Demand Cost.*

Capacity Load Factor. The ratio of the number of kw.-hrs. actually generated to the number of kw.-hrs. that would be generated in a given period, were the plant operated continuously at full rated capacity; the average kw. load, divided by the kw. capacity of the generating station. See *Station Load Factor,* and see *Connected Load Factor.*

Connected Load. The total kw. capacity of all the motors (output capacity), lamps (input capacity), and current consuming devices connected to a given circuit.

Connected Load Factor. The ratio of the metered kw.-hrs. to the number of kw.-hrs. that would be consumed during a given

period if the connected load were consuming current at its full rated capacity. Unless otherwise stated, the assumed period is a year of 8760 hrs.

Cost. The sum of operating expenses, taxes, depreciation annuity, and interest, but not including profit. (See *Profit* and see *Expense.*)

Consumer Cost. The cost that can be charged directly against each consumer, in distinction from Demand Cost and Output Cost. (See *Service Cost.*)

Demand Cost. This term is used by the Wisconsin Railroad Commission as a synonym for *Capacity Cost*, which latter term was originally coined by Henry L. Doherty. In Volume 4 of its decision, p. 662, the Wisconsin Commission gives this definition: "The expenses which are thus chargeable to demand are sometimes said to consist of all expenses which do not depend on output (kw.-hr.) and at other times, again, of all expenses which go on or continue even if the plant is shut down. . . . Experience shows that it is difficult, if not impossible, to lay down a definition that will apply under all conditions."

In view of this indefiniteness, and particularly in view of the Wisconsin Commission's error of prorating interest and depreciation charges among Demand Expense, Output Expense and Consumer Expense, in proportion to those several expenses (see *Distribution cost*), we prefer not to use the term "demand cost."

Demand Factor. The ratio of the Active Load to the Connected Load. The reciprocal of the Demand Factor is the Consumer's Diversity Factor. (See *Diversity Factor.*)

Depreciation Annuity. The annuity deposited in a sinking fund to replace plant units at the expiration of their economic life. This does not include the cost of *repairing* parts of plant units, such as the flues of a boiler, the cost of which is provided for by current maintenance expense. (See *Functional Depreciation* and *Natural Depreciation.*)

Distribution Cost. The cost of distributing the current from the substation to consumer, which embraces interest, depreciation, and taxes on the distribution system, including customer's transformers and the operating expense (including proportion of general expense) attached thereto. Although Distribution Cost has no logical relation to Demand Cost, as the latter term is used by the Wisconsin Commission, it corresponds rather closely to it in dollars and cents.

Diversity Factors. Due to the fact that all customers do not simultaneously require current enough to run their connected loads to full capacity, but have a diversity of demand, the number of kws. of station capacity is always less than the number of kws. of connected load. If there were no losses of current, the Total True Diversity Factor would be the quotient obtained by dividing the Total Connected Load by the Station Peak Load. However, there are always losses of current (transmission, transformation, etc.). Hence, if the Total Connected Load is divided by the Station Peak Load, the quotient is the Total *Apparent* Diversity Fac-

tor. Apparent Diversity Factor is, then, the product of True Diversity Factor by Line Efficiency. (See *Line Efficiency.*)

Just as there are successive efficiencies, the product of which gives the combined or total efficiency, so there are successive diversity factors, the product of which gives the total true diversity factor.

The successive diversity factors are:

1. Meter Diversity Factor.
2. Transformer Diversity Factor.
3. Substation Diversity Factor.
4. Station Diversity Factor.

Meter Diversity Factor is the quotient found by dividing the connected load of a group of meters (customers) by the peak load at the line transformer that serves the group.

Transformer Diversity Factor is the quotient found by dividing the sum of the peaks of a group of line transformers by the peak on the feeder wire that serves the group.

Substation Diversity Factor is the quotient found by dividing the sum of the peaks on a group of feeder wires by the peak on the substation bus bar that serves the group.

Station Diversity Factor is the quotient found by dividing the sum of all the substation peaks by the peak at the station.

Each of these four diversity factors is an "apparent diversity factor" if line losses are not eliminated, but each becomes a "true diversity factor" if line losses are eliminated.

The Active Load (see definition) divided into the Connected Load gives a quotient that might be called the *Customers' Diversity Factor.* The reciprocal of this is the Demand Factor. (See *Demand Factor.*)

Efficiency. The quotient found by dividing the power generated into the difference between the power generated and the power lost, or $E = (P - L) \div P$. (See *Line Efficiency.*)

The efficiency of water wheels, generators, and transformers decreases as the load upon them decreases. Hence the all day average efficiency is less than their efficiency at capacity load.

Expense. As here used, expense means operating expense and does not include fixed charges. (See *Cost.*)

Fair Return Rate. The percentage rate of annual fair return on the value of the property. The sum of the Interest Rates and Profit Rates.

Fixed Charges. The sum of Interest, Depreciation Annuity, and Taxes.

Full Cost Rate. A rate of charge that includes all prorated expenses, fixed charge and profit. (See *Additional Cost Rate.*)

Functional Depreciation. Depreciation due to economic inadequacy and obsolescence. (See *Natural Depreciation.*)

General Expense. This includes operating expenses not directly assigned to Generating or Production Expense and to Distribution Expense. As here used, it does not include Taxes, which are frequently classed under General Expense.

Interest Rate. The annual percentage paid for capital that is well secured. It does not include Profit. (See *Profit.*)

Kilowatt (kw.) = 1.34 Horse Power (h.p.).

Kilowatt-Hour (kw.-hr.) = 1.34 h.p.-hrs.

Line Efficiency. The term as here used includes not only the efficiency of the transmission and distribution lines but of the step up and step down transformers, line transformers, and customers' meters.

Load Factors. See *Capacity Load Factor, Connected Load Factor* and *Station Load Factor.* Unless otherwise stated, all load factors are for the full year of 8760 hrs.

Maintenance Expense. The current expense for upkeep, including current repairs and renewals, but not including Depreciation Annuity, which latter may well be regarded as a depreciation reserve.

Natural Depreciation. Depreciation that results from the action of the forces of nature — rot, rust, abrasion, wear and tear, and the like. (See *Functional Depreciation.*)

Operation Expense. All operating expenses exclusive of maintenance.

Operating Expense. All expense of operation and maintenance. This does not include Fixed Charges. (See *Fixed Charges.*)

Output Cost. The cost (of electric current) that is a function of the kw.-hr. output of the station. There is no agreement among rate experts as to what costs are a function of output. In a steam plant the fuel cost is clearly a function of output, but it is often contended that practically all other station expenses are fixed and independent of output. On the other hand, there are those who regard practically all expenses of operating the generating station, transmission line and substations as being Output Expenses. Some, like the Wisconsin Railroad Commission, regard most of the fixed charges on the generating plant, transmission line and substations as being Output Costs. They also prorate other Fixed Charges, as well as General Expense, between Demand Expense, Consumer Expense and Output Expense, in proportion to the direct distribution of these three classes of expenses.

Peak Load. The maximum (short time) kw. load during a given period, which period unless otherwise stated, is a year. The *Station Peak Load* is the maximum (short time) load at the generating station.

Plant Unit. An appraisal unit of plant, such as a generator, a building, a pole, etc.

Profit. The balance left after deducting Operating Expenses and Fixed Charges from Gross Operating Income. Fair profit plus interest is Fair Return.

Production Cost. The cost of generating, transmitting, and transforming at the substation. This includes all operating expense and fixed charges on the power plant, transmission lines and substations, plus its assigned part of General Expense. This Production Cost corresponds roughly with what the Wisconsin Railroad Commission includes under Output Cost. But it differs in

that no other fixed charges are assigned to the Production Cost than those directly assignable to the producing system, i. e., the power plant, transmission system and substations. It also differs in that General Expense is not arbitrarily prorated to Production Cost in proportion to a so-called "output expense," but only such General Expenses are allotted to Production Cost as would be incurred were current produced for *wholesale* at the substations. That this is a rational treatment of the problem is well seen when one proceeds to determine a fair wholesale rate for power at the substation. The Production Cost gives the proper wholesale rate at the substation for any given station load factor created by the customer.

Rate. A charge for service. It should include cost plus profit.

Repairs. Renewals of parts of a Plant Unit.

Real Diversity Factor. See *Diversity Factor.*

Service Cost. This includes the operating expenses and fixed charges that pertain to the service connections and customers' meters, plus clerical and other general expense involved in caring for customers' accounts, collecting bills, and the like.

Station Load. The load in kilowatts at the power station.

Station Load Factors. The ratio of number of kw.-hrs. actually generated to the number of kw.-hrs. that would be generated in a given period were the plant operated continuously at the *peak* load of the period. Unless otherwise stated, the period is a year of 8760 hrs. Stated otherwise, the Station Load Factor is the average kw. station load divided by the peak load. (See *Capacity Load Factor.*)

Rates based on full cost. It is assumed that every rate of charge for electric current is based on the full cost plus a fair profit.

Classification of Cost Items. For rate making purposes, the cost of electric current can best be distributed under three heads:

1. Production Cost.
2. Distribution Cost.
3. Service Cost.

As stated under the definition of Production Cost, this part of the cost corresponds rather closely to what the Wisconsin Railroad Commission calls Output Cost. However, the methods used by the Wisconsin Commission in prorating General Expense and Fixed Charges among Demand, Output and Customer Expenses, do not seem logical. Accounting authorities are cited by the Wisconsin Commission in support of prorating "indirect expenses" (General Expense and Fixed Charges) according to the distribution of "Direct Expenses," but a careful study of the writings of those accounting authorities will show that their experience has been limited to mercantile and manufacturing pursuits, where interest, depreciation and taxes were a relatively small part of the total cost. When we come to consider public service companies in general, and hydro-electric companies in particular, we find that fixed charges assume large proportions.

This difference between mercantile and utility companies is con-

ceded. At once we are struck by the incongruity of prorating the fixed charges of a hydro-electric plant according to the distribution of the direct operating expense. To do so is to make the tail wag the dog; we might almost say, to make the hair on the end of the tail wag the dog. Interest and depreciation are not direct functions of direct operating expense, as assumed by the old accounting authorities. In fact, interest and depreciation are more apt to be inverse or reciprocal functions of direct operating expenses. Thus, in a steam plant, the direct operating expense is large in proportion to the fixed charges, whereas in a hydro plant the reverse is true. The absurdity of many a general rule is best disclosed by applying it to extreme cases, and nowhere does the prorating of interest and depreciation according to direct operating expense show forth with greater absurdity than in the case of a large hydro-electric plant.

For these reasons, and because the wholesale price of current at the substation must so frequently be determined, the cost of current has been classified as above shown. Production Cost then becomes the full cost of current at the substation, and it includes all operating expense and fixed charges incident to generating, transmitting and transforming the current at the substation.

Production Cost. Production Cost of a given plant may be regarded as being composed of two classes of cost items: (1) Fixed Cost, and (2) Variable Cost.

Fixed Cost includes all fixed charges (interest, depreciation and taxes) and all operating expenses that are not affected by increase or decrease in kw.-hr. output. Variable Cost includes only the costs that vary with the output. In the case of a hydro plant the variable costs are almost infinitesimal compared with the fixed costs, unless a value is assigned to the water used. In the case of a steam plant, the variable cost consists almost entirely of the fuel cost.

Therefore, the Production Cost per kw.-hr. of a hydro plant varies inversely as the station load factor. With a steam plant the same holds true of practically all costs except fuel. The fuel cost would be a constant cost per kw.-hr. were it not for the lower efficiency of the generating plant at lower loads.

Having calculated the total annual Production Cost for a hydro plant determine the kw.-hr. cost of a 100% station load factor. For other station load factors of a hydro plant the kw.-hr. production cost will be inversely as the station load factor.

The Station Load Factor assignable to any class of customers is estimated by multiplying the True Diversity Factor (assignable to that class) by their Connected Load Factor. Thus, if residence lighting customers have a true diversity factor of 5 and a connected load factor of 4, their station load is 20%. In the case of a hydro plant whose Production Costs are as tabulated below, the production cost at 20% Station Load Factor would be 1.25 cts. per kw.-hr. if there were no line losses, or 1.67 cts. per kw.-hr. if losses were 25%.

TABLE V. PRODUCTION CHARGE PER KW.-HR. IN CENTS

Station load factor per cent.	No loss	Transformer and line losses 10%	15%	20%	25%	30%
100	0.25 cts.	0.28 cts.	0.29 cts.	0.31 cts.	0.33 cts.	0.36 cts.
90	0.28	0.31	0.33	0.35	0.37	0.40
80	0.31	0.34	0.36	0.39	0.41	0.44
70	0.36	0.40	0.42	0.45	0.48	0.51
60	0.42	0.47	0.49	0.52	0.56	0.60
50	0.50	0.56	0.59	0.62	0.67	0.71
40	0.63	0.70	0.74	0.79	0.84	0.90
35	0.71	0.79	0.84	0.84	0.95	1.01
30	0.83	0.92	0.98	1.04	1.11	1.19
25	1.00	1.11	1.18	1.25	1.33	1.43
20	1.25	1.39	1.47	1.56	1.67	1.79
15	1.67	1.85	1.96	2.09	2.23	2.39
12	2.08	2.31	2.45	2.60	2.77	2.97
10	2.50	2.78	2.94	3.12	3.33	3.57

Checking Estimated Apparent Diversity Factors. From the above given definitions of Diversity Factors it is evident that apparent diversity factor may be expressed by the formula

$$d = d_1 \times d_2 \times d_3 \times d_4 \times E \quad \ldots\ldots\ldots\ldots (16)$$

That is, apparent diversity factor is the product of successive True Diversity Factors and Line Efficiency. Line Efficiency is itself a product of successive efficiencies, including an average all day efficiency factor. (See *Line Efficiency.*)

Station Load Factor assignable to any class of customers may be expressed by the formula

$$l = \frac{df}{E} \quad \ldots\ldots\ldots\ldots (17)$$

f being connected load factor.
E " line efficiency.

It should be remembered that, in equity, each class of customers is entitled to benefit from the general diversity of use of the current by different kinds of customers at different times of the day or year. Thus if the peak of a railway load is 1,200 kws. on the railway circuit, while the peak of the lighting load is 1,800 kws. on the lighting circuit, and, if the two peaks are not simultaneous, it may happen that the station peak is only 2,500 kws. This would give a Station Diversity Factor (d_4) of

$$3000 \div 2500 = 1.2$$

Both classes of customers are equally entitled to the benefit of this diversity factor, if a full cost rate is to apply.

Likewise, if a class of irrigating customers use current only 6 summer months during the year, at full load, while a class of lighting customers use current only during the remaining 6 months at their full load, there is a resulting Station Diversity Factor (d_4) of 2 from this cause alone, assuming that there are no other circuits.

Great care must be exercised in allowing for class diversity of

the sorts just indicated, for they frequently cause a very high Station Diversity Factor, or Class Diversity Factor.

The Apparent Diversity Factor assigned to any class of customers must be based on the record of loads for the entire year, and must be the product of the four classes of successive diversity factors, i. e. Meter, Transformer, Substation, and Station Diversity Factors.

We may now develop two important rules for checking any estimates as to diversity factors for different classes of customers of a given plant, and a rule for calculating Station Load Factor.

Rule I. Divide the Total Connected Load of each class of customers by its Apparent Diversity Factor, and the quotient will be its prorata of the kw. station peak load. The sum of these quotients for all classes of customers is the station peak load during the year.

Rule. II. Multiply the Connected Load of each class of customers by its Connected Load Factor, and the product will be the kw.-hrs. sold annually to that class of customers. The sum of these products for all classes of customers is the total kw.-hrs. sold annually.

Rule III. Multiply the True Diversity Factor of each class of customers by its Connected Load Factor and the product is the Station Load Factor assignable to that class.

It will be found that if Rule 1 is applied to the electric rate cases that have been handled by public service commissions, some surprising errors as to assumed diversity factors will often be disclosed. Also it is noteworthy that the existence of successive diversity factors, whose product is the total diversity factor of a given class, has not usually been recognized. Finally, it has seldom been perceived that there is such a thing as an Apparent Diversity Factor as distinguished from a True Diversity Factor. In other words, the effect of Line Efficiency has been lost sight of.

Distribution Cost. To the Production Cost must be added a Distribution Cost chargeable to all customers who do not buy their current at the substation. The Distribution Cost includes all operating expenses and fixed charges that pertain to the distribution system. The distribution system includes poles, wire, line transformers, etc., between the substation and the customer's "service." Any part of the General Expense that would be incurred if the distribution system were operated independently of the rest of the plant, should be allotted to the Distribution Cost. Parts of the distribution system can be charged directly against certain classes of customers: thus, street lighting circuits are chargeable to the municipality. Other parts of the distribution system are used in common by two or more classes of customers, and must be prorated. Perhaps the best theory of prorating is the *Separate Plant Theory.* According to this theory, the cost of the separate plant for each class of customers is calculated, and the existing plant is prorated according to the respective costs of the separate plants that would be required if the classes of customers were served entirely independently of one another.

A close approximation to this theory is obtained by applying

what may be called the *Peak Load or Demand Theory.* According to this theory, the cost of a plant, or part of a plant, that is used in common by several classes of customers is prorated among them according to their peak demands. This is the theory most commonly used by rate making engineers for prorating costs of plant; but in prorating operating expenses it is often best to go back to the Separate Plant Theory to get a clear idea of the most rational distribution of expenses that are common to two or more classes served.

Having prorated the cost of the distribution system to the different classes of customers, it is usually fair to charge to each customer his prorata according to his connected load, for it is highly probable that at some time or another he will use his entire connected load to its full capacity. Active load might be used as a basis of such prorating, in special cases, but there is usually little known as to active load, and where it is known, it is usually found to be a fairly uniform percentage of connected load for any given class of customers. Hence it seems to us not only confusing, but of doubtful value to split hairs by trying to introduce an individual Active Load element in a rate case.

Service Cost. This includes the operating expenses and fixed charges that pertain to the service connections and customers' meters, plus the clerical and other general expense involved in caring for customers' accounts, collecting bills, advertising for and soliciting new customers, and the like.

Reading, inspecting, and maintaining customers' meters comes under this cost heading. So do customers' repairs and renewals, as well as renewals of incandescent lamps, where such renewals are paid for by the Company. Office rent is to be prorated to Production Cost, Distribution Cost, and Service Cost, on the separate plant theory. And the same holds true of the salaries of general officers, insurance, and other general expenses.

Formulas for Calculating Costs and Rates. The above enumerated costs of electric current can be concisely expressed in formulas that clearly show the relation of the different constants and variables. The formulas will serve not only as a basis for equitable rate making, but for a study of the economics of generating, transmitting and distributing current.

The following formulas give the *costs,* but to use them for determining *rates* it is merely necessary to make the Fixed Charges include the Profit as well as the Interest on the investment.

Symbols

C = total annual Service Cost for all customers.
c = annual Service Cost per customer.
D = total Apparent Diversity Factor for the plant.
d = Apparent Diversity Factor for a given class.
d_1 = True Meter Diversity Factor for a given class.
d_2 = True Transformer Diversity Factor for a given class.
d_3 = True Substation Diversity Factor for a given class.
d_4 = True Station Diversity Factor for a given class.
E = total line Efficiency.
e_1 = Customers' meter efficiency.

e_2 = Customers' transformer efficiency.
e_3 = Feeder line efficiency.
e_4 = Substation efficiency (step down).
e_5 = transmission line efficiency.
e_6 = step up transformer efficiency.
e = ratio of all day efficiency to the peak load efficiency.
F = total Connected Load Factor (annual).
f = Connected Load Factor (annual) of given class.
G = total annual Distribution Cost.
g = annual Distribution Cost per k.w of Connected Load of a given class.
h = Fixed Annual Cost per kw. of Connected Load of a given class.
K = kw.-hr. average cost for all classes.
k = k.w.-hr. cost for a given class.
L = total Station Load Factor.
l = Station Load Factor of a given class.
m = Annual Fixed Distribution and Service Cost per customer of a given class.
n = number of kw. connected load of given customer or of a typical customer of a given class.
p = Production Cost per k.w-hr.
R = Total annual Fixed Production Cost when the Station Load Factor is 100%.
r = ditto per kw. of Station Peak Load.
s = Variable Production Cost per kw.-hr. (i.e. cost of fuel) which constitutes nearly all the Variable Production Cost.)
T = total yearly cost for entire plant.

$$k = \left(\frac{r}{8760\,lE} + \frac{s}{E}\right) + \frac{g}{8760\,f} + \frac{c}{8760\,fn} \quad \ldots\ldots\ldots (18)$$

$$h = g + \frac{c}{n} \quad \ldots\ldots\ldots (19)$$

$$p = \left(\frac{r}{8760\,lE} + \frac{s}{E}\right) \quad \ldots\ldots\ldots (20)$$

$$m = gn + c \quad \ldots\ldots\ldots (21)$$

$$d = (d_1\,d_2\,d_3\,d_4)\,E \quad \ldots\ldots\ldots (22)$$

$$E = e_1\,e_2\,e_3\,e_4\,e_5\,e \quad \ldots\ldots\ldots (23)$$

$$l = \frac{df}{E} \quad \ldots\ldots\ldots (24)$$

For rate making purposes it is usually sufficiently exact to assign roughly approximate value of E to all residence and business lighting customers; but in the case of large power customers more precision should be used.

Formula for k.w.-hr. costs:

$$k = \left(\frac{r}{8760\,lE} + \frac{s}{E}\right) + \frac{g}{8760\,f} + \frac{c}{8760\,fn} \quad \ldots\ldots\ldots (25)$$

The three terms in the right hand member of the equation are respectively the kw.-hr. Production Cost, the kw.-hr. Distribution Cost, and the kw.-hr. Service Cost.

The values of k may be plotted in a curve for any assumed values

of d and n, the abscissas of the curve being f (the connected load factor), and the ordinates being k (the correspondence kw.-hr. cost). Since for different classes of customers there are different values of d (d being a function of l as in Equation 24) and n, it is necessary to plot different cost curves for the different classes.

As above stated, the Variable Production Cost (s) consists almost entirely of the fuel cost. In a hydro plant, s may be regarded as having no appreciable existence, unless a value is assigned to the water itself.

Fuel cost per kw.-hr. is commonly regarded as being constant for any given plant, and for any given price of fuel. It is, however, constant only where the load is constant. A variable load causes variation in generating and transforming efficiency, which often causes wide fluctuation in the cost per kw.-hr. for fuel. Due allowance should be made for this when estimating s.

Formulas for Two Payment Rates. It is frequently desirable to charge a fixed annual (or monthly) rate (h) per kw. of connected load plus a kw.-hr. rate (p) on the total kw-hr. used. To do this it seems best to determine the fixed annual kw. rate by adding the Distribution Cost to the Service Cost. Then the Production Cost is used as the basis for the kw.-hr. rate.

Then we have

$$h = \left(g + \frac{c}{n} \right) \text{for the connected kw. rate} \; \ldots\ldots\ldots\ldots (26)$$

$$p = \left(\frac{r}{8760\, l E} + \frac{s}{E} \right) \text{for the kw.-hr. rate} \; \ldots\ldots\ldots\ldots (27)$$

It might be argued that in the case of a hydro-electric plant nearly all the costs are fixed, and that the logical rate would therefore consist almost entirely of a large fixed kw. connected load rate plus a very small kw.-hr. rate. This, however, would lead to the use of small installations which would be run almost continuously, whether the current was really needed or not. The great objection to flat rates arises from this very reason. There is, besides, an innate prejudice against rates that do not result in substantial decreases in monthly charges when current is used sparingly.

Formula for Minimum Rates. Equation (26) gives a rational "minimum annual cost" per kw. of connected load. If it is desired to express this as a minimum annual cost per *customer*, we have

$$m = gn + c \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

It has been argued by some that only c, the Service Cost, should be regarded as the minimum cost, but this ignores the fact that the distribution system stands ready to serve the customer, and that he should be at least willing to pay his prorata of the fixed charges thereon. Indeed, it may rationally be claimed that the minimum rate should be high enough to include the customers' prorata of the fixed charges on the power plant, transmission line

and substations, based on the customers' demand thereon. It is good business, however, to stop short of this last claim, and it is evident that this belief is quite general, for the standard $1 per month minimum charge for residence lighting customers is far below what is necessary to cover a customer's prorata of all the fixed charges of the average plant.

In applying formula (28), there may be some doubt as to the value of n (the connected kw. load) of a customer of a given class. It seems fair to select on average value of n, found by dividing the total connected load of all the customers of a given class by the number of customers in that class. If we were to go to the extreme of selecting the connected load of the smallest customer, the probable result would be to lead to a still further decrease in the number of lamps installed by the smallest customer, which in turn would result in a decided decrease in the diversity factor of customers of that class, and a consequent rise in the Production Cost for customers of that class. In brief, lowering of the minimum rate charged to lighting customers, if based on a very small connected load, would result in a lowering of the diversity factor, and a rise in the Production Cost. Hence, the minimum rate cannot usually be lowered without making it necessary to raise the kw.-hr. rate.

Finally, it is impracticable to keep a careful check on the connected loads of the smallest customers, for they can readily substitute larger lamps for smaller and change their loads.

For these reasons, it seems fair to assume an average value for n, in any given community.

Cost of Oro Electric Corporation Power Plant, Transmission Lines and Substations. Having discussed the general methods to be used in analyzing the kw.-hr. cost of current, we come to an application of the principles to the City of Stockton, California.

The first step in the analysis is to estimate the cost of the proposed hydro-electric plant to be built on Yellow Creek and the cost of the transmission lines and substations necessary to convey and transform the full amount of current that will be generated The following is the itemized estimate of this cost:

TABLE VI. ESTIMATED COST OF CONSTRUCTING YELLOW CREEK POWER PLANT AND TRANSMISSION LINES.

(38,000 kw.) Voltage on main conductors, 130,000.

ROADS, RAILWAYS AND CONSTRUCTION PLANT

1.	Roads	$ 30,000
2.	Railway spur	50,000
3.	Railway to quarry for dam	20,000
4.	Incline	20,000
5.	Power line (less salvage)	30,000
6.	Tools, constr., equip., camps, etc.	100,000
7.	Railway along flow line (pays for itself by timber hauled out and sold)	.....
	Total — Roads, rys., etc.	$ 250,000

DAMS AND HEADWORKS

Humbug Dam:

8.	Excavation, 23,000 cu. yds. at $1	$ 23,000
9.	Rock Fill, 140,000 cu. yds. measured in the dam at $1.50	210,000
10.	Concrete toe, 2,600 cu. yds. at $10	26,000
11.	Timber face, 480 M at 25	12,000
12.	Spillway	30,000
13.	Gate house, gates, etc.	20,000
	Total — Humbug Dam	$ 321,000
14.	Other headworks	12,000
	Total for dams and headworks	$ 333,000

CANALS AND CONDUITS

Forest Conduit:

15.	Tunnel (5 by 7½) 5,200 ft. at $12	$ 62,400
16.	Adit, 100 ft, at $10	1,000
17.	Ditch, 84,000 cu. yds. at $0.50	42,000
18.	Culverts, waste gates, etc.	6,000
	Total for Forest Conduit	$ 111,400

Cataract Conduit:

19.	Wood stave pipe (7 ft., 94 ft., b.m. per lin. ft., 183 lbs. bands and 48 lbs. shoes, nuts, etc., per lin. ft. 19,560 lin. ft. at $15	$ 293,400
20.	Steel Pipe at bends, 236,000 lbs. at $0.08	18,800
21.	Excavation (mostly along present ditch), 26,000 cu. yds. at $0.75	19,500
22.	Back fill, 12,000 cu. yds. at $0.50	6,000
23.	Trestle, 1,100 ft. at $8	8,800
24.	Manholes, 8 at $200	1,600
25.	Tunnel (7 ft., 2.7 cu. yds. excav. and 1.0 cu. yd. concrete per lin. ft.) 12,900 lin. ft. at $30	387,000
26.	Tunnel adits, 4,000 cu. yds. at $6	24,000
27.	Pipe at adits, 86,000 lbs. at $0.07	6 000
28.	Manholes and bulkheads	5,000
	Total for Cataract Conduit	$ 770,100

Butt Creek Conduit:

29.	Ditch trimmed, 3,200 lin. ft.	$ 3,200

Surge Pipe, etc.:

30.	Surge pipe or shaft	$ 20,000
31.	Pipe through dam, 170,000 lbs. at $.07	11,900
	Total for Surge pipe, etc.	$ 31,900
	Total for Canals and Conduits	$ 916,600

PRESSURE PIPES

32.	Tunnel (12 ft.) 6,400 cu. yds. at $6	$ 38,400
33.	Excavation, 30,000 cu. yds. at $2.50	75 000
34.	Concrete (anchors, etc.) 1,000 cu. yds. at $0.12	12,000
35.	Steel pipe —	
	680,000 lbs. (riveted) in tunnel at $.07	47 600
	630,000 " " at $0.065	40,950
	4,550,000 " lap welded at $0.075	341,250
36.	Manholes, etc.	10,000
	Total for Pressure Pipe	$ 565,200

POWER STATION

		Per k.w.	
37.	Power house	4.47	$ 170,000
38.	Excavation, 10,000 cu. yds. at $2.00	0.53	20,000
		5.00	
39.	Water wheels, gates and governors	4.35	165,000
40.	Generators, exciters, etc.	4.20	160,000
41.	Switchboard and wiring	2.63	100,000
42.	Step up transformers	2.36	90,000
43.	Crane, etc. (50 ton)	0.26	10,000
44.	Heating and miscel.	0.26	10,000
	Total for Power Station	19.06	$ 725,000

MISCELLANEOUS BUILDINGS

45.	Operator's quarters, etc.	$ 30,000
46.	Machine shop, equip., etc.	20,000
	Total — Miscel. Bldgs.	$ 50,000
	Total power plant (Items 1 to 46)	$ 2,839,800
47.	Contingencies and overhead charges, 30% of items 1 to 46	851,940
	Total power plant	$3,691,740

TRANSMISSION LINES

48.	Steel towers (660 ft. apart), 190 miles at $2,300	$ 437,000
49.	Copper for 190 miles of tower line (6 wires), 3,250,000 lbs. at $0.19	617,500
50.	Labor string, wire on towers: 1,030 miles at $40	41,200
51.	Insulators (9,100) on towers, 56,000 elements (10 lb.) at $1.25	70,000
52.	Hardware for above	10,000
53.	Grounding wire	10,000
54.	Telephone 190 miles at $125	23,750
55.	Fencing and misc.	25,000
56.	High towers, etc.	25,000
57.	Switching stations	14,000
58.	Pole transmission lines:	
	100 miles at 1,600	160,000
	100 miles at 1,000	100,000
	Total for items 48 to 58	$1,333,450
59.	Contingencies and overhead charges 25% of items 48 to 58	333,360
	Total for Transmission Lines	$1,666,810

WATER RIGHTS, LAND, ETC.

60.	Water rights, land and right-of-way	$ 600,000

SUBSTATIONS

61.	Sectionalising Stations	$ 50,000
62.	Substations for 38,000 kw. at $8	304,000
63.	Tie line transformers	60,000
64.	Regulating apparatus	25,000
	Total for Substations, etc.	$ 439,000
65.	Contingencies and overhead charges, 25% of items 61 to 64	$ 109,750
	Total for Substations, etc.	$ 548,750
	Grand Total for (38,000) kw. plant complete	$6,507,300

SUMMARY

Roads, rys. and const. plant	$ 250,000
Dams and headworks	333,000
Canals and conduits	916,600
Pressure pipes	565,200
Power station	725,000
Misc. bldgs., etc.	50,000
Total	$2,839,800
Contingencies and overhead charges, 30% of above items.	851,940
Total power plant, 38,000 kw. at $97	$3,691,740
Transmission lines	$1,333,450
Contingencies and overhead charges on same, 25%	333,360
Total transmission lines	$1,666,810
Water rights, land and right-of-way	$ 600,000
Substations, etc	$ 439,000
Contingencies and overhead charges 25% on same	109,750
Total substations, etc.	$ 548,750
Grand Total, 38,000 kw. at $171	$6,507,300

Cost of Electric Current at the Substation. Careful gaugings that have extended over nearly 8 years show that there will be sufficient water to develop at least 19,000 continuous kws. or 38,000 kws. on a 50% load factor. This can be done with a flow of 165 sec.-ft.; but, as a matter of fact, there has been no time in the last 8 years when 179 sec.-ft. could not have been averaged had there been a storage reservoir of the size planned. The 165 sec.-ft. has been assumed in order to provide for the possibility of two very dry years in sequence. It will be pointed out later that the full 179 sec.-ft. and even more, can be profitably utilized if a steam auxiliary plant of about 4,000 kws. is provided.

Assuming for the present only 38,000 at a 50% load factor we have 164,600,000 kw.-hrs. generated annually. The production cost of this current at the substations will be shown to be 0.5 ct. per kw.-hr. on the assumption that none of the current is lost in transmission and transforamtion (step up and step down). And with a 10% loss the cost at the substation will be 0.56 ct. per kw.-hr. The deduction of this cost follows.

Annual Operating Cost. We shall now consider only the cost of operating the plant down to and including substations, reserving for later discussion the cost of distribution and service cost. The following will be the annual operating expense of the power plant, transmission lines and substations, exclusive of repairs and depreciation:

Power Plant Expense:	
Wages and supplies	$ 32,000
Transmission Line Expense:	
Wages, supplies, etc.	8,000
Substation Expense:	
Wages, supplies, etc.	26,000

General Expense:

Salaries	28,000
Rentals	4,000
Insurance, legal and damages	15,000
Miscellaneous	10,000
Total general expense	$ 57,000
Total operating expense, exclusive of maintenance	$123,000

Annual Current Repairs on a plant of as permanent a character as this will not exceed 1% of the total plant cost. For many years to come the repairs will be less than 1%. In addition to Current Repairs, a depreciation annuity of 2% of the plant investment should be earned. This 2% set aside annually and compounded at 5% interest will amortize the entire investment in 25 years.

It is expected that capital can be secured by the sale of bonds, etc., at such rates that the interest charge will be 7% on the cost of the plant. Hence the annual repairs, depreciation and interest total 10%, distributed thus:

	Per cent.
Current repairs	1
Depreciation annuity	2
Interest	7
Total	10

Since the investment in the plant, up to and including substations, will be $6,500,000, we have the following annual cost:

Interest, repairs and depreciation (10% of $6 500,000)	$650,000
Operating expense, exclusive of maintenance and taxes	123,000
Taxes on the above	52,000
Total annual production cost	$825,000

As above stated, 164,600,000 kw.-hrs. will be generated annually. Hence, the Production Cost is $825,000 \div 164,600,000 = 0.50$ ct. (half a cent) per kw.-hr. generated. If we assume a transformer and transmission line loss of 10%, the cost of current distributed at the substations will be $90\% \div 0.50 = 0.555$ ct. per kw.-hr. when the station load factor is 50%.

Table V gives the Production Cost per kw.-hr. for any given Station Load Factor assignable to any given class of customers, and for any given losses of current involved in the step up and step down transformers, transmission, distribution and metering.

Cost of Current for Residence Customers. Having calculated the production cost for various Station Load Factors we can determine the total cost of current per kw.-hr. sold to residence customers.

At the low price proposed by the Oro Electric Corporation, the average residence customer can be counted upon to create a Station Load Factor of at least 20%. This is equivalent to a connected load factor of 4.5%, and a True Diversity Factor of 4.5, the product of these being 20%, or the Station Load Factor. In other words, the average residence customer with a connected load of 0.75 kw. will use 300 kw.-hrs. per annum.

Referring to Table V, we see that for a Station Load Factor of 20% and a Line and Transformer Loss of 25%, the Production Cost is 1.67 cts. per kw.-hr., to which must be added the Stockton (Cal.) local tax of 2%, making a total production cost of 1.71 cts. To this must be added the Distribution and Service Costs, which are as follows:

For the average residence customer there will be the following investment in Distribution System:

	Per customer
Poles, etc.:	
0.5 pole at $13 in place	$ 6.50
1.2 cross arm and hardware at $1.25	1.50
Total poles, etc.	$ 8.00
Wire, etc.:	
35 lbs. at 0.21 (including labor, pins, insulators, etc.) in place	$ 7.35
Transformers:	
0.5 kw. at $12 in place	6.00
Miscellaneous:	
Telephone, tools, stores, etc.	2.65
Total	$24.00
Contingencies and overhead charges, 25%	6.00
Total per residence customer	$30.00

(Note. Service connection and meter are given later.)

The interest, depreciation and repairs on this investment of $30. per residence customer are:

	Per cent.
Interest	7
Depreciation and repairs	6
Total	13

The annual distribution charge per residence customer is:

	Per customer
Interest, depreciation and repairs 13% of $30	$3.90
Salaries, insurance, etc.	0.40
Taxes	0.30
Total, 300 kw-hrs. at 1.53 cts.	$4.60

Hence the distribution cost is 1.53 cts. per kw.-hr.

The investment in service connection and meter is as follows per residence customer:

	Per customer
Service connection	$ 4.00
Meter	12.00
Total	$16.00
Contingencies and overhead charges, 25%	4.00
Total per residence customer	$20.00

The interest, depreciation and repairs on the service and meter are as follows:

	Per cent.
Interest	7
Depreciation and repairs	8
Total	15

In addition to this annual cost of 15% on the $20. investment (or $3 per year) per residence customer for service connection and meter, there is a service expense of $4 per annum, which is itemized as follows:

Salaries of officers	$0.30
Accounting	1.00
Billing and collecting	0.60
Rate clerk, etc.	0.30
Stationery and printing	0.20
Bad accounts and cut outs	0.10
Meter reading and transfer	0.40
Soliciting and advertising	0.20
Telephone, telegraph, etc.	0.20
Rent	0.20
Miscellaneous (legal, insurance, etc.)	0.50
Total service expense per customer	$4.00

(Note. Part of the salaries of officers is to be found under Production Cost and part under Distribution Cost, and the same holds true of certain other items.)

Summing up the Service Cost per residence customer per annum, we have:

	Per customer
Interest, depreciation and repairs, 15% of $20	$ 3.00
Service expense	4.00
Taxes	0.50
Total, 300 kw.-hrs. at 2.50 cts.	$ 7.50

Summing up the average kw.-hr. cost for residence customers, we have:

	Cts. per kw.-nr.
Production cost	1.71
Distribution cost	1.53
Service cost	2.50
Total cost per residence	5.74

The base rate proposed for residence customers is 6.5 cts. and the average residence customer will fall within this rate, for the rate does not begin to decrease until a customer uses more than 100 kw.-hrs. per month. In considering the Connected Load Factor, it should be remembered that a lower price for current causes a greater consumption, and consequently a greater Connected Load Factor. A customer having a net rate of 6 cts. per kw.-hr. uses much more current than a customer having an 8-ct. rate.

Cost of Current for Business Lighting Customers. Following the same method of cost analysis above applied to residence customer rates, we shall consider the three items of cost per kw.-hr. for business customers: (1) Production Cost; (2) Distribution Cost, and (3) Service Cost.

The average business lighting customer will create a Station Load Factor of at least 25%, and, referring to Table V, we see that the Production Cost is 1.33 cts. per kw.-hr. when the Station Load Factor is 25% and the line losses are 25%, adding 2% for local tax we have 1.36 cts. per kw.-hr. as the production cost.

The Distribution Cost is derived as follows:

The average business customer with 1.6 kw. connected load will require an investment of less than $208 in underground conduits, underground service, cables, transformers, etc. (exclusive of meters and outside service connections, which are a part of the service cost). This distribution system cost is estimated liberally as follows per kw. of connected load:

		Per kw.
Ducts:		
100 ft. vitrified ducts at 35 cts.		35.00
Manholes:		
.03 manholes at $175	$5.25	
.08 manholes at $90	7.20	12.45
Switches, etc. in Manholes:		
Junction boxes, switches and miscellaneous		4.00
Laterals and Risers:		
0.2 Lateral (3 in. pipe, 60 ft.) at $75		15.00
Cable:		
30 ft. lead covered cable in ducts at $0.70	$21	
20 ft. cable in laterals at $0.20	$4	25.00
Transformers:		
0.8 k.w. at $10.00		8.00
Miscellaneous:		
Stores, etc.		5.00
Total		$104.45
Contingencies and overhead charges, 25%		26.10
Total underground system		$130.55

The annual interest depreciation and repairs on the underground distribution system will be:

	Per cent.
Interest	7
Depreciation and repairs	5
Total	12

The annual Distribution Cost per kw. of connected load will be:

Interest, depreciation and repairs 12% of $130.55	$15.67
Operation expense	1.50
Taxes	1.43
Total annual distribution cost per k.w.	$18.60

Hence a business lighting customer averaging 1.6 kws. of connected load should be charged with an annual Distribution Cost of $1.6 \times \$18.60 = \$29.76$.

The average business lighting customer has a Connected Load Factor exceeding 11%, and a True Diversity Factor exceeding 2.5,

making a Station Load Factor exceeding $11\% \times 2.5 = 27.5\%$. The annual consumption of current by the average business customer having 1.6 kw. connected load exceeds 1,500 kw.-hrs. Hence dividing the $29.76 by 1,500 kws. we have 2.00 cts. per kw.-hr., which is a liberal estimate of the Distribution Cost for business customers in the "underground district."

The investment in meters and in the individual services (not included in the underground system above given) will be as follows, per business customer:

	Per customer
Service (in addition to underground service)	$10.00
Meter	15.00
Total	$25.00
Contingencies and overhead charges, 25%	6.25
Total individual service and meter	$31.25

The annual interest depreciation and repairs will be:

	Per cent.
Interest	7
Depreciation and repairs	7
Total	14

Hence, the annual Service Cost per business customer will be:

	Per customer
1. Interest, depreciation and repairs 14% of 31.25	4.37
2. Service expense (previously estimated)	4.00
3. Taxes	0.63
Total service cost	$9.00

Since the average business customer uses at least 1,500 kw.-hrs. per annum, the Service Cost will be less than $\$9 \div 1{,}500 = 0.60$ ct. per kw.-hr.

Summing up we have the following kw.-hr. cost of current sold to the average business lighting customer:

	Cts. per kw.-hr.
Production cost	1.36
Distribution cost	2.00
Service cost	0.60
Total	3.96

The base rate for business lighting customers is 6 cts. per kw.-hr. up to 95 kw.-hrs. used in a month. Then the rate drops to 5.8 cts. for current used up to 125 kw.-hrs. per month. Then the next drop is to 5.6 cts. per current used up to 160 kw.-hrs. It is evident, then, that the average business customer who used 1,500 kw.-hrs. per year, or 125 kw.-hrs. per month, will enjoy a rate 5.6 cts. per kw.-hr., less the discount for prompt payment.

CHAPTER II

DEPRECIATION, REPAIRS AND RENEWALS

Depreciation. Depreciation is loss of value. It may occur as a result of the loss of useful life of a plant-unit or its parts or because of the invention or design of a more efficient plant unit, or because a larger plant unit is more economic, or in consequence of a drop in the prices of equivalent plant units, or because of accidental injury, or in consequence of any change that makes it more economic to render an equivalent service with another plant-unit.

The cost of renewing an entire plant-unit is properly called a depreciation cost or charge. The cost of renewing a part of a plant unit is properly called a repair expense. But, as is stated below in the discussion of the term Plant Unit, there has been no very clear recognition of this important distinction by accountants and engineers.

Careless writers of recent years and almost all writers ten or more years ago, usually have made no distinction between the annual cost of repairs and the annual charge for depreciation or depreciation annuity. Consequently many estimates of operating costs are deceptive. Two other causes of error as to "upkeep costs" (i.e. combined repair and depreciation costs) are common: (1) Failure to distinguish between natural and functional depreciation; (2) Failure to equate repair costs of the entire life of the plant unit. Both of these factors will be discussed later.

For ordinary purposes it is well to classify depreciation under two general heads: (1) Natural Depreciation and (2) Functional Depreciation.

Natural Depreciation is loss of value due to physical or chemical changes in plant units, e.g., rot, rust, electrolysis, "wear and tear." Loss of value due to an accident, such as the burning out of a generator, may also be classed as natural depreciation.

Functional Depreciation is loss of value due to (a) obsolescence, (b) inadequacy, or (c) drop in prices. Obsolescence arises wholly from "improvements in the art"— inventions. Inadequacy arises from increased demands upon plant-units rendering them economically too small or too light for the increased service required. Drop in prices occurs as a result of any combination of causes that increases the supply relative to the demand. Natural depreciation is attributable to the forces of nature, whereas functional depreciation is attributable to the forces of society.

The forces that commonly cause Natural Depreciation are: (1) Chemical action, (2) electrical action, (3) mechanical action, and (4) vital action. Rust is an example of chemical action; electrolysis is an example of electrical action; abrasion or wear is an example of mechanical action; rotting of wood is an example of

vital action, as is also the progress of senility of animals resulting finally in death.

The forces that commonly cause Functional Depreciation are: (1) Invention, (2) growth of business that renders a plant unit inadequate economically, (3) public enactment that causes either loss of part or all of the economic use of a plant unit, (4) competition that results in a reduction in unit prices.

It needs but to make these classifications of the causes of depreciation to give us pause when we undertake to say that any single simple method of estimating accrued depreciation can be applicable to all these sorts of depreciation. *Inspection*, for example, may disclose approximately the amount of wear that has occurred in the piston and cylinder of an old pump, but mere inspection may not disclose whether an old pump is as economic in the use of fuel as a new one. *Testing* alone will demonstrate the fuel efficiency of pumps. Testing alone, however, will not show the depreciated value of a pump or of any other apparatus that is to be compared with some apparatus of standard value. To make such a comparison accurately we must apply mathematics, even though it be of a very simple sort, as will be shown later.

Plant Units and Their Relation to Depreciation. Before any clear cut distinction can be drawn between terms such as "cost of repairs," "cost of renewals," "maintenance expense," and "depreciation annuity," it is essential to define what a plant unit is. No book on accounting or ratemaking gives a definition of plant unit, consequently there is endless debate as to the "true meaning" of all terms relating to "upkeep costs."

Plant Unit is any unit to which a unit cost is assigned. Since the cost of a machine may be split up into many units to each of which a unit cost may be assigned, it follows that appraisers may differ greatly as to what they call a plant unit. We prefer to call a whole machine — such as a generator or a boiler — a plant unit, and to treat the depreciation of the machine as a whole. The expense due to loss of life of the parts of the machine, we prefer to classify under the term *Repairs*. Plant units such as the following have been used: A pole, a square yard of pavement, an engine, a building, a pound of copper wire, etc.

Obviously it is possible to group the elements of a plant into "units" of any desired size and class. Thus an entire transmission line may be called a "plant unit." If that is done, then the renewal of separate poles would be a repair expense, and only the renewal of the entire transmission line would be a depreciation charge.

A single pole with its cross-arms, guys, insulators, etc., but not including the transmission wires, may be regarded as a plant unit. In that case the renewal of a cross-arm would be a repair expense. But even a cross-arm may be regarded as a plant unit, in which case its renewal would be a depreciation charge.

Although no attempt has ever been made to define every plant unit of a given plant — except in ratemaking cases — still it has usually been the practice in accounting to treat all short lived

small priced elements as chargeable to repairs when renewed, while renewals of long-lived, high-priced elements have been charged to depreciation. Railway ties, and even rails are commonly charged to "current maintenance," or "repairs," when renewed; whereas locomotives, bridges, and buildings would be charged to a depreciation fund if such a fund existed. In the absence of depreciation funds built up from depreciation annuities and interest thereon, railways and other corporations have charged renewals of every sort to "current maintenance."

It is important to know how to avoid the endless confusion that still exists in accounting and cost estimating, because of lack of definitions of what are to be regarded as plant units. It is equally important to know that this confusion is so universal as to make much of the published matter on repair expense and depreciation costs of doubtful value. With this warning, the authors must leave the reader to his own interpretation of many "upkeep costs" given in this book.

Weighted Average Age of Plant Units. The average age of any group of plant units of equal value is calculated thus: Multiply the total number of plant units of the same age by the number of years that they have been in use; add together all such products for the given class of units, and divide the sum by the total number of plant units. The quotient is the average age of the given class of plant units.

If the plant units of a given class vary in first cost, then the *weighted average age* is found thus:

Multiply the money expended each year in the construction of the plant units now in existence by the age in years; add those products together and divide by the total cost. The quotient is the weighted average age of the given class of plant units.

In applying this last rule, care must be taken to make adjustments needed to provide for fluctuations in unit prices, so that standard unit prices may be applied to all. Care must also be taken to ascertain whether any plant units as originally built have been renewed; and to this end both the original construction accounts and the maintenance and renewal reserve accounts should be investigated.

If practically all the structures shown in the accounting records are still in existence, and the money expended each year for each class of structure is known, it is a very simple matter to figure the average age of the money invested in such structure, which, after all, is what is needed in estimating present value. To illustrate, suppose there are a number of station buildings in existence, whose age is not known. Suppose, however, that $10,500 was spent for such buildings in 1896, $20,000 in 1900, and $5,000 in 1902. Then, in 1906, the average age of the money invested in these buildings is ascertained thus:

$10,500 x	10 yrs.	equals	$105,000	one year
$20,000 x	6 yrs.	equals	$120,000	one year
$5,000 x	4 yrs.	equals	$20,000	one year
$35,500 x	7 yrs.	equals	$248,500	one year

This gives a total of $35,500 invested 7 yrs.; for $35,500 × 7 yrs. equals $248,500 one year.

The rule to be followed in all such cases is to multiply the money expended each year for structures of a given class by the age in years, add all these products together, and divide by the total cost of all the structures under consideration. The quotient is the average age of all the structures, or, more strictly speaking, the average age of the money invested in the structures. If some of the structures are no longer in existence, this method can still be applied. Take railway cross-ties, for example. Ascertain the total value of cross-ties in the track, then go back through the records of cost and tie renewals, by years, until the total cost of the renewals adds up to the total value of ties now in the track. Then compute the average age as above shown. If the price of ties has fluctuated, ascertain the actual price paid, and reduce all yearly expenditures of renewals to the present price.

Analysis of Maintenance Accounts and Upkeep Costs. Before the true net earnings of a plant can be accurately ascertained, it is necessary to analyze the maintenance accounts, for it will usually be found that the actual expenditures for upkeep in any given year are less than the average expenditures for upkeep will be in the years to come. Simply because a plant is old it must not be assumed that its upkeep expenditures have reached a normal or average condition. Yet this erroneous assumption has been made in many rate making cases.

Upkeep Cost is the actual expenditure for current repairs and current renewals (maintenance) plus the depreciation annuity not provided for in the actual expenditure for renewals.

Current Maintenance, or maintenance as the term is commonly used by accountants, is the actual expenditure for current repairs and current renewals.

Repair Expense is the current expenditure for keeping the *parts* of plant units in serviceable condition.

Renewal Expense is the current expenditure for the renewal of whole plant units, and does not include a depreciation annuity.

Annual Depreciation, as used here, is the estimated annual loss of value from all causes, including natural and functional. Annual depreciation usually exceeds annual Renewals in plants that are not very old. Hence the extreme importance of not assuming that annual renewals are probably sufficient to cover annual depreciation. Annual renewals are usually only a part of annual depreciation, and annual depreciation is, in turn, only a part of annual upkeep cost, for annual depreciation does not include annual repairs. Great confusion still exists in the minds of many people as to these terms, partly because they are not used in the same sense by all engineers. Serious errors have occurred, both on the part of public service companies and public service commissions, in estimating the probable annual upkeep cost. Sometimes in such estimates, annual repairs have been omitted, but more often the error has arisen because actual annual renewals of the previous year were assumed to cover all probable annual depreciation.

It has been proposed to use the term "maintenance" in place of "upkeep cost," and to segregate it into "ordinary maintenance" and "deferred maintenance." Then "ordinary maintenance" would cover repairs and renewals "which are made each year as needed"; while "deferred maintenance" would cover repairs and renewals "which cannot economically be made each year but which are made at frequent intervals." Engineers who propose such a classification have evidently never kept corporation books.

Many careless estimators have not used the term "annual depreciation" to cover renewals of parts (or repairs) as well as renewals of entire plant units, but have actually forgotten to include an allowance for repairs. When it is considered that the repairs of steam locomotives annually average 18% of their first cost, whereas the renewals of entire locomotives are about 4%, it will be appreciated that an engineer who estimated only 4% for depreciation of locomotives and allowed nothing additional for repairs would fall into serious error. Yet precisely this sort of blundering occurs with considerable frequency, and largely because of failure to understand the meaning of the term "annual depreciation."

Method of Estimating Annual Upkeep Cost. Having defined terms as we shall use them and having briefly explained accounting practice as to certain important features, we may pass to a summary of the proper method of estimating the annual upkeep cost of a public utility plant.

As at present conducted, no public utility company keeps its accounts in such a manner as to segregate Maintenance Expenses into Repairs and Renewals, using these terms as above defined. Yet, if we are to make proper estimates for depreciation funds, or if we are to ascertain the "true operating expense," it becomes essential to analyze Maintenance into Repairs and Renewals.

If the weighted age of any given set of plant units is less than half the total life of units of that class, the expenditures for Renewals of the plant units are below what they must ultimately be. Thus, if the life of interurban railway cross-ties is 10 years, and if the weighted age of a given lot of ties is 3 years, it is evident that tie renewals are still below normal. When, however, the weighted age becomes 5 years (i.e., half the life), it is evident that tie renewals have reached a normal stage, for there will then be ties of all gradations of age, from those just put in the track to those just ready to be taken out.

If the weighted age of few classes of plant units in a plant has yet reached half the total life, it becomes exceedingly important to analyze the maintenance accounts. Otherwise, if the present maintenance expenditures were regarded as being normal, no adequate allowance would be made for depreciation that is now going on but is not yet being paid for.

In the same manner current repairs increase with increasing age of the plant units. Hence neither Repairs nor Renewals can be properly judged until an analysis is made of the maintenance accounts and until the weighted age of each class of plant units is determined.

Maintenance, as before said, is the cost of Repairs plus the cost of Renewals of such plant units as have been charged to the operating account. When a plant is young, repairs are usually inexpensive and there may be a few or no renewals of plant units at all. Hence, unless a renewal reserve account is provided, there may be little or no charge for annual plant depreciation shown on the books, although depreciation is actually occurring. When a large plant is old, there are heavy repair expenses which are quite uniform but the actual renewals of many classes of plant units fluctuate from year to year. In other words, the annual expenditures to replace plant units are apt to fluctuate, and the fewer the number of plant units the greater the fluctuation.

Having analyzed the annual maintenance expenses of a plant so as to show what has been expended for Renewals and what for Repairs, the next step is to compare the actual expenditure for Renewals with the estimated annual Depreciation. In the case of most plants it almost invariably happens that the actual Renewal expenditures fall below the estimated annual Depreciation.

The true total upkeep expense is the sum of two items: (1) Repairs and (2) Depreciation. While the actual maintenance expense is the sum of two items: (1) Repairs and (2) Renewals. Since Depreciation usually exceeds Renewals and always exceeds it in the case of a new plant, it is of the utmost importance that the excess be accurately ascertained before passing upon the question of rates charged for service.

Suppose, for example, that the estimated depreciation of crossties is 8% per annum, and that the total cost of the ties is $20,000, then the annual depreciation is $1,600. If the actual tie renewals for a given year show a cost of $600, it is evident that tie renewal costs for that year are $1,000 below normal.

Where the number of plant units of any given class is large, and where they are of varying ages, a normal condition of renewals is not reached until the weighted age of all the plant units of that class is half the total life of a plant unit of that class. Keeping this fact in mind, it is possible to tell roughly whether or not the renewals of a given class of plant units have been normal during a given year, provided only that we know the weighted age of the plant units. But the more precise method to use is the one above outlined, which may be summed up thus:

Segregate the actual annual maintenance expenses into Repairs and Renewals. Deduct all the Renewals and add the estimated annual Depreciation. The resulting sum will be the total true annual upkeep cost.

When nothing but the ordinary accounting records are available, the segregating of Renewals from Repairs often seems like an impossible task in the case of certain classes of expense items, but usually a way can be found that will enable a sufficiently close approximation to be made. A study of the "stock slips," for example, will disclose the purposes for which given amounts of materials were used. Having ascertained the amount of materials

(copper wire, for example) used for renewals, the labor required to put the given length of wire in place may be estimated.

Some maintenance accounts, like those for ties and rails, contain only the cost of materials used for renewals. In such cases, also, the labor of placing these materials in the plant can be estimated, and then added to the cost of the materials.

The "requisitions" show all the purchases of equipment, and a study of the equipment and accounting records discloses whether a given purchase was for Renewals or for additions to plant.

Suggested Improvements in Maintenance Accounting. Since public service commissions will hereafter limit net income to a "reasonable return," it becomes of prime importance so to keep the maintenance accounts as to segregate Repairs from Renewals. To this end a company should subdivide its maintenance accounts so as to show the labor cost corresponding to the cost of each class of materials used in Repairs and Renewals. Every maintenance cost item should not only be divided into labor and materials, where such division is practicable, but Repairs should be segregated from Renewals. It is also desirable that there be a separate maintenance account for every plant distribution account. Thus, if there is a plant account for bridges, there should be a corresponding maintenance account for bridges, and this account should be subdivided into Labor and Materials. By providing a maintenance account corresponding to each class of plant items, it will be possible to express each kind of annual maintenance cost as a percentage of the first cost of the corresponding plant items.

The method above suggested for recording maintenance expenses is not in use by any public service company, so far as we know, but the necessity for securing more accurate maintenance data to be used in rate making cases alone justifies the adoption of this method. Furthermore it will enable any one better to judge past maintenance expenses and to predict future upkeep costs with greater accuracy.

Analysis of Upkeep Cost. In estimating the probable annual cost of upkeep, plant units should be segregated into two groups:

Group I:

Those plant units of a given class (railway ties, for example) that are numerous and of all gradations in depreciated value from nearly zero to 100% value.

Group II:

Those plant units of a given class that either are not very numerous, or if numerous, do not have much gradation in depreciated value.

In the first group would fall railway ties, if the railway were one in which ties of every gradation in age were to be found in the track. Likewise poles of a distribution system would come in the first group, if the poles were of all gradations in age. In such cases the average age of the plant units is 50% of the total life of a plant unit of that class. Obviously no depreciation fund is needed

in that case, for the annual renewals will be made according to the straight line formula. Thus, if poles have a life of 17 years, and if they are of all ages from brand new to nearly 17 years old, the normal renewals will be at the rate of 6% per year. Renewal of plant units in Group I is therefore to be calculated by the straight line depreciation formula.

Renewal of plant units in Group II is to be calculated by the sinking fund formula, the sinking fund annuities being made only sufficient to amortize the depreciated value (not the new value) of the given plant units. If the plant units are of a kind whose repairs to parts of a unit will rise as time goes on, then the unit cost depreciation formula is the one to apply in estimating increments in future upkeep.

Amortization Before or After Depreciation Has Occurred. Contention is often made that depreciation should be amortized *after* a renewal has been made and not *before*. Where only natural depreciation is involved, there is little to support such a contention. But where functional depreciation is involved, the contention takes on more force. It is then reasoned as follows:

Functional depreciation of a particular old plant is always attended by functional appreciation of the property due to the economic advantage of the new plant that displaces the old. The cost of this depreciation is less than the profit of the appreciation, and out of this profit must be paid the cost of depreciation. Therefore no charge should be made for functional depreciation until there is a gain accrued with which to meet the charge, that is, until the saving effected by the new plant provides funds with which to amortize the investment in the plant displaced.

Thus, it is contended, does the burden fall where and when it is due, whereas to anticipate functional depreciation by setting aside annuities before the functional depreciation occurs, results in assessing costs prior to the enjoyment of benefits.

It is but one step from this conclusion to the next: Functional depreciation is non-existent until the old plant is actually removed. In other words, functional death does not occur until the inadequate or obsolete plant is permanently retired.

This last proposition is seriously supported by many men, but is untenable. On the other hand, there is some justification for the view that functional depreciation should be amortized *after* the fact, although the justification is upon grounds not hitherto clearly set forth.

Before correct answers can be given to the questions here involved, it is necessary to distinguish sharply between the economics of free competition and the economics of full or partial monopoly. It is also necessary to distinguish between economic improvements caused by forces *exterior* to an owner or employe of a plant and economic improvements caused by the owner or employé of a plant — *interior* forces. Competition and other exterior forces may compel an action; but complete, and often even partial monopoly, may lead to non-action.

An invention made by men exterior to a public utility company,

for example, may force the company to buy the improved apparatus in order to protect itself from possible competition, or in order to meet existing competition. In such an event, functional depreciation cannot always be amortized out of subsequent gains. This is the condition that exists for most manufacturers, and makes it imperative for them to insure themselves either through a functional depreciation annuity or through large profits *prior* to the occurrence of the anticipated improvement. Even they can usually amortize some of the functional depreciation *after* the fact, because of the partial monopoly that every well established business enjoys.

Functional depreciation caused by forces over which the owner of a plant has little or no control is closely akin to loss of property by fire. It should be insured against as far as possible and in advance. If such depreciation strikes the man who has built up no reserves against it, his property is as surely and almost as swiftly swept away as by a conflagration. Hence the fallacy of the generalization that all functional depreciation should be amortized after the fact. Hence, too, the fallacy that *no* property has functionally depreciated until it has actually been retired. Such generalizations evidently need decided qualifications, to which we now come.

Invention by men *exterior* to a plant is to be provided for by a functional depreciation reserve built up prior to the invention, as far as possible. Invention by men *within* the plant usually needs no such protection. This distinction is vital to any complete theory of accrued depreciation and depreciation reserves. Invention from *without* may cause a sudden and irretrievable loss of value to a given plant. Invention from *within* also causes destruction of existing property value but the loss is not irretrievable and is, in fact, never incurred unless there is overpowering belief in the ability to recoup it out of savings effected by the particular invention. The enjoyment of the fruits of the invention is assured in one or more ways: (1) Patents, (2) secrecy, (3) inertia of competitors, (4) monopoly of the business, partial or complete. Where invention is not patentable, some sort of partial or complete monopoly of the business is usually the source of the protection needed to stimulate the effort to secure improvement. This holds also of all economic improvements whether or not they are entitled to be ranked as inventions.

Economic improvement from *within* an organization occurs only under the stimulus of some sort of protection in the enjoyment of its benefits, and in that case the depreciation that it causes is properly amortized *subsequent* to the fact. But economic improve- from *without* an organization results in a depreciation that should be insured against, as far as possible, in *advance* of the fact.

Every industrial invention is a gain to society at large, but whether it is a gain to any particular group of men depends upon their partial or complete protection from the competition with the invention for a period of time. In the absence of such protection, an invention may cause great loss of property to some men.

When through the enjoyment of a franchise or of an established business, or both, a public utility company has gained the protection that a partial monopoly secures to it, the custom has been to amortize functional depreciation *after* its occurrence. This is entirely defensible, either as an economic or an ethical proposition. Where such a policy has existed, it is certainly not ethical for a government to change the policy by a sudden fiat, thus depriving a company of the opportunity to amortize its functionally retired plant units. And even were it ethical to do so, it would be uneconomic for a government thus to destroy a company policy by fiat, for the inevitable result would be to stop almost every effort to economize further. Certainly no company would initiate improvements under such conditions and it would be equally certain to put every obstacle in the way of improvements initiated by others.

In ascertaining the depreciated value of a plant, only the *actual depreciation* should be deducted from the cost new. But in creating depreciation or renewal funds for future use, not only should provision be made for the natural depreciation that is *certain* to occur, but for all the functional depreciation that will *probably* occur, provided only that the annual surplus after paying operating expenses and a fair return on the investment is large enough to permit the creation of such a depreciation fund. Only the most profitable companies can do this. During the "development period" no company should attempt to provide a fund for future functional depreciation, for functional depreciation may not occur, although it is probable that it will.

In brief, a financially strong company should provide a fund to amortize probable functional depreciation in *advance* of its occurrence, while a financially weak company should pay for functional depreciation only when it occurs and should amortize such depreciation *after* its occurrence. Intermediate between these extremes will be found many companies that provide depreciation funds or surpluses to take care of *part* of the probable functional depreciation.

In the event that no depreciation fund is to be provided for future functional depreciation, the rate of fair return on the investment should be high enough to cover probable functional depreciation.

Stated otherwise, in making provision for the *future,* the probable future functional depreciation due to future inventions, future growth, etc., must be fully provided for, either in the form of depreciation funds or in a rate of "fair return" sufficiently high to recoup the investor for the chance he takes that functional depreciation will reduce the value of his plant. Perhaps the most rational plan is to use a combination of these two methods by: (1) Providing a depreciation fund that will include all probable depreciation due to inadequacy, predicated upon the past growth of demand upon the plant and upon similar plants elsewhere; and (2) permitting a rate of fair return sufficiently high to provide for probable depreciation due to obsolescence.

Accrued Depreciation and Depreciated Value. Taking the original cost of a plant unit as the base cost, and deducting from this base

the depreciated or present value, the remainder is its *accrued depreciation.* In an ideal system of accounting and financial management, there would exist a *depreciation fund* equal to the sum of the accrued depreciations of all the plant-units. Such an ideal system would provide a depreciation fund out of which would be paid all current repair expenses as well as the cost of renewing entire plant-units. This ideal is seldom attained in practice.

Depreciated value is often spoken of and regarded as being "second-hand value," but to do so is a mistake. *Second-hand value* is the net price that a used plant-unit will bring in the open market. The day after a new machine is put into use it can rarely be sold for as much as it cost. Frequently it will not bring half its original cost even though perfectly new. This is partly due to the expense incurred in marketing it, but largely to the distrust with which any used machine is viewed by prospective purchasers.

Obviously, then, the second-hand value of an old plant-unit is not necessarily its depreciated value, provided the owner of the plant-unit can find further economic use for it.

Depreciated value of a plant-unit is its economic worth as an instrument of production, which worth is correctly ascertainable by the application of the unit cost depreciation formula hereinafter explained. In this formula, as will appear later, the standard of value by which any plant-unit is rated is the unit cost of production or service with the most economic plant-unit available for the given service. It is impracticable to define true depreciated value completely in a few words, without the use of some expression or term that must itself be defined in the form of a rule or formula involving several elements of the unit cost depreciation formula (which will be deduced later) may be expressed in words thus:

Ascertain the total cost per unit of product (or service) that the old plant-unit yields, and deduct therefrom the corresponding total unit cost of product that the most economic new plant-unit yields; multiply this saving in unit cost by the number of units annually produced by the old plant-unit and capitalize this total annual saving by dividing by the interest percentage. The quotient is the accrued depreciation of the old plant-unit, which, subtracted from its original cost, gives its depreciated value.

This formula gives results that sometimes approximate those obtained by more commonly used formulas; but it can and will be demonstrated that it is the only depreciation formula that is strictly rational and perfectly general in its applicability.

The commonly used (but less general and often erroneous) depreciation formulas are three in number:

1. The Straight Line Formula.
2. The Declining Balance Formula.
3. The Sinking Fund Formula.

Each of these formulas will be briefly discussed before passing to the Unit Cost Depreciation Formula. Four terms must first be defined, but it should be noted that there is no general acceptance of these definitions.

Recovery Value, or "recoverable value," is the net value remain-

ing in a plant unit upon the expiration of its natural or functional life. Of course, it is understood that we are now speaking of its life in its particular place in the plant under consideration. Recovery value is salvage value minus cost of removal.

Wearing Value, or "service value," is the difference between the cost new and the recovery value of a plant unit. Therefore "wearing value" is the only part of the value that depreciates.

Scrap Value is the selling price of an old plant unit that has so depreciated as to be worthless for further service in any part of any plant until it has been re-manufactured. The term applies to many metals that can be used again after re-melting, re-rolling, and the like.

Salvage Value is the selling price of an old plant unit after its removal. It can never be less than its scrap value, and may be considerably more if the plant unit can be used again in a plant without being entirely re-manufactured.

The term *"Minimum service value"* is sometimes used instead of salvage value; but it is also used to denote the least value arbitrarily assigned to a plant unit still in service. One author (Foster) has confused these two meanings and has given erroneous data of salvage value.

Recovery value may be less than salvage value or even less than scrap value, as happens when the cost of removing a plant unit is greater than the price for which it will sell as scrap. This is illustrated in the case of a small pipe, the cost of excavating which may exceed its scrap value. In paved streets, even fairly large pipes may at times have little or no recovery value, because the cost of taking up and relaying the pavement alone exceeds the salvage value. Of course where a trench for a new pipe is to be dug at the time of the abandonment of the old pipe, the same trench may serve to rescue the old pipe and then its recovery value and salvage value may be almost identical. This is particularly true where trenches are in rock, for it then is usually wise to re-use the old trench for the new pipe.

Wearing value is sometimes defined as the difference between the original cost of a plant unit and its scrap value or its salvage value, thus giving wearing value two meanings, depending on which subtrahend is used.

To the majority of plant units it is often useless to assign any scrap value in calculating accrued depreciation, for the scrap value is usually so insignificant a part of the cost new that to use it all gives an appearance of great accuracy to the depreciation calculations where no great accuracy exists.

Per Cent. Condition. Depreciated value of plant units is often denoted by their "per cent. condition." Thus, if the depreciated value of a generator that originally cost $10,000 is $8,000, its "condition" is 80%. Instead of using the original cost as the base, it is common also to use the cost of reproduction new as the base for estimating per cent. condition. The percent of annual depreciation used for a depreciation annuity is usually a percentage of the original cost new; but occasionally it is a percentage of the

wearing value. Still less frequently it is a percentage of the cost of reproduction new.

Straight Line Depreciation Formula. Expressed verbally this formula is as follows: The depreciated value of a plant unit is found by multiplying its wearing value by its age in years and dividing by its total life in years, and adding this quotient to its scrap value. In other words the percent of annual depreciation of the wearing value is found by dividing the total life of the plant unit into 1. Thus if the life of a pole is 20 years, it depreciates annually 5% of its wearing value. If such a pole has no salvage value, then its annual depreciation is 5% of its original cost.

The straight line formula is simple, and for very short lived plant units it may serve sufficiently well for many purposes. But it has no other merit than its simplicity to commend it, and for long lived plant units it yields results that are grossly erroneous. Curiously enough there are still some engineers who regard the straight line formula as being quite as defensible logically as any other. Most engineers, however, concede that it is purely empirical, and that its only justification is that it gives results, in some special cases, that approximate the truth. We may perhaps be pardoned for suggesting here that if all engineers were to give as much study to logic as they give to mathematics, there would be none left to defend the rationality of the straight line depreciation formula.

The Declining Balance Depreciation Formula. (Often called the Progressive Diminution Formula.) The rule for this formula is: The annual depreciation of a plant unit during a given year is a fixed per cent. of its depreciated value at the end of the preceding year; hence the annual depreciation progressively diminishes, and the depreciated value is found by subtracting the sum of these diminishing depreciation annuities from the original cost of the plant unit.

This formula produces a curve of depreciated value that rapidly flattens out and extends to infinity. It has never had vogue among engineers but has been extensively used by accountants. The supposed merit of this formula is that in the early years when plant repairs are small, the formula yields a higher depreciation annuity than in the later years when the repairs are large; and thus a relatively constant annual sum of repairs and depreciation is attained. At best this is a very crude way of attaining a proper annual upkeep charge; yet granting that the formula may occasionally serve well enough for such a purpose, there is no defense for it on rational grounds. For plant units that require no renewal of parts before their life expires, this formula is clearly erroneous; and since there is no fixed mathematical relation, for any kind of plant, between current repair, expense and depreciation annuity, the formula has no rational defense.

Sinking Fund Depreciation Formula. According to the sinking fund method of calculating depreciation, it is assumed that the accrued depreciation of a plant unit is the amount already accumulated in a sinking fund that was begun when the plant unit was

first put into service, and whose annuities are such that at compound interest the amount at the end of the life of the plant unit will equal the first cost of the plant unit.

The argument upon which the sinking fund depreciation formula was originally advocated is this: The purchaser of a depreciated plant should be willing to take the plant at its first cost, providing he also were to receive an accumulated sinking fund that would eventually (at the end of the life of the plant) equal the first cost of the plant. Hence if the purchaser takes only the depreciated plant, he should take it at its cost new less the accumulated sinking fund.

This argument is sound, provided the plant unit is of a kind whose operating expenses, current repairs, and service performed, remain constant throughout the life of the plant unit. But the argument is unsound when operating expense and repairs increase or when the service or output of the plant unit decreases as it grows older. In brief, the sinking fund depreciation formula is a special case formula — although one of wide applicability. The sinking fund depreciation formula is a special case of the unit cost depreciation formula, as proved on page 101.

See Gillette's "Handbook of Cost Data," p. 35 et seq. for tables, to be used in applying the sinking fund formula, and p. 798 for depreciation curves.

Defects of Straight Line and Sinking Fund Depreciation Formula. We may be sure that the straight line formula and the sinking fund formula cannot both be theoretically correct. One must be merely an approximation if the other is correct. Which, if either, is correct?

Accrued natural depreciation increases as time increases, if the forces of nature have a progressive effect. In the case of rot, rust, wear, etc., the resulting accrued depreciation can often be determined from consideration of the age of the plant units, provided the amount of previous repairs is known. But in the case of functional depreciation, age of plant has no direct relation to its accrued depreciation. Invention may render a new plant almost valueless, even before it has seen service or but shortly after its initial use. Growth of business, which causes inadequacy, may be rapid or slow, largely dependent on the vigor of the management of the property, partly on a rise in general prosperity (itself largely a result of invention), and for other reasons not directly related to the lapse of time. Clearly, then, it is not logical to insert a *functional life* in either the "straight line" or the "sinking fund" formulas for accrued depreciation. Natural life is to be inserted in these formulas if they are to be applied at all. Yet how rarely has this vital distinction been drawn. Tables of "average life" of plant units commonly used by appraisers contain lives that are for the most part functional lives, in some part composite lives, and only in small part natural lives. The data in these tables were originally compiled, for the most part, as a basis for calculating depreciation annuities, with which to establish depreciation funds — a thing entirely distinct from accrued depreciation. Thus a fire

insurance fund might be established exactly as a functional depreciation fund is established. A building not yet burned has certainly not lost value because a fire insurance fund exists to insure it. In perfectly analogous manner, a plant has not lost value because of a functional depreciation fund that exists to insure it against obsolescence and inadequacy.

We see, therefore, that the two common depreciation formulas have been misused, usually with resulting depreciated values far below the real depreciated values. Let us next examine the formulas themselves to see whether they are defensible at all.

If the straight line depreciation formula be applied to a 10-year-old cedar pole having a total natural life of 20 years, its depreciated value is 50 per cent. of its cost new. Assuming the pole to cost $10 new and to have no salvage value, it would be worth $5 at the end of ten years, according to that formula. If this deduction is correct, it should be impracticable for a purchaser to use the pole during its remaining life at a less annual cost than would be incurred if he bought a new pole. Let us, therefore, compare the annual costs.

	Old pole
Interest, 5% of $5	$0.25
Depreciation, 10% of $5	0.50
Total annual cost for old pole (10 years remaining)	$0.75

	New pole
Interest, 5% of $10	$0.50
Depreciation, 5% of $10	0.50
Total anual cost for new pole	$1.00

Hence, the old pole, purchased on a straight line depreciation formula, can be used at a less cost per annum than a new pole. This absurd result indicates that the straight line formula gives too low a value. The proof of absurdity is complete if we show that a sinking fund annuity applied to each price ($5 and $10) yields likewise different annual costs.

	Old pole
Interest, 5% of $5	$0.25
Depreciation annuity, 7.95% of $5	0.39
Total annual cost for old pole	$0.64

	New pole
Interest, 5% of $10	$0.50
Depreciation annuity, 3.02% of $10	0.30
Total annual cost for new pole	$0.80

Hence a sinking fund cannot be used to secure equal annual costs where depreciated value is derived by the straight line formula, and in no case is it possible to use a new pole at less annual cost than an old pole, if the old pole is purchased at depreciated value calculated by the straight line formula. Therefore, a rational seller would never part with a pole at a depreciated value thus calculated, unless under some sort of compulsion.

Let us now apply the same sort of reasoning to the sinking fund depreciation formula, assuming the same conditions as to age and

cost new of pole. A 5 per cent. sinking fund established to redeem a \$10 pole in 20 years would amount to \$3.80 in 10 years. Hence the sinking fund depreciation formula gives \$10.00 — \$3.80 = \$6.20 as the depreciated value of the pole. Then for the old pole, we establish a sinking fund to redeem the \$6.20 in the remaining 10 years, which requires an annuity of 7.95 per cent.

	Old pole
Interest, 5% of \$6.20	\$0.31
Depreciation annuity, 7.95% of \$6.20	0.49
Total annual cost for old pole	\$0.80
	New pole
Interest, 5% of \$10	\$0.50
Depreciation annuity, 3.02% of \$10	0.30
Total annual cost for new pole	\$0.80

Whatever be the age of the old pole, a similar calculation shows a constant annual cost of \$0.80. It follows, therefore, that a rational seller would part with the pole at a depreciated value established by the sinking fund formula, provided he were put to no loss from causes incident to the sale.

Note carefully that in the above examples nothing but natural depreciation is involved and that no repairs or renewals of parts occur. If repairs to a composite plant unit are involved in the problem, neither of these two formulas is correctly applicable. And, as shown above, neither is correctly applicable if functional depreciation is involved.

The sinking fund depreciation formula takes no cognizance of maintenance expense, which constitutes a serious defect in the formula when applied to classes of plant units that have a rising curve of repairs. Curiously enough this defect in the formula has been spoken of as if it were a merit. It has been said, for example, that a sinking fund depreciation curve follows closely the curve of actual loss of value, dropping slowly in the early years but dropping very rapidly toward the close of life of the plant. In brief, the argument has been that actual loss of value coincides closely with a sinking fund depreciation curve. Granting that it did, the result would be entirely fortuitous. In fact, however, repair "curves" are not regular curves but jagged lines. One of the prime objects of a depreciation reserve is to secure equality of annual charges for upkeep by providing a reservoir that prevents violent fluctuations in annual maintenance charges. Normally the repair costs on a machine rise as the machine grows older, but, instead of providing for this rise, the sinking fund depreciation formula, as commonly used, entirely ignores it. Thus, the sinking fund formula gives as high a percentage of depreciated value for an automobile as for a horse, if each is assumed to have same life and if both are the same age. Yet the automobile has a rapidly rising curve of repairs, while the horse has no repairs.

If a sinking fund were calculated for every renewable *part* of a composite plant unit, of course the sinking fund depreciation formula could be correctly applied in the case of natural depre-

ciation. But this is obviously not the common method of applying the formula. It will be shown that the sinking fund depreciation formula is a special form of a much more general and perfectly correct depreciation formula. Under certain limitations, therefore, it has a field of usefulness.

Rational or Unit Cost Depreciation Formula. It has been maintained that depreciated value is "purely a matter of judgment" and that it can be arrived at either with or without the aid of formulas. That judgment plays an important part in estimating any value, depreciated or undepreciated, is true, but that judgment unaided by formulas can determine value is not true where the operating expense is a factor in the value.

Given the choice between an old and a new plant unit, each capable of yielding the same service or output, the new plant unit would be selected unless the old plant unit were procurable at a price such that "fixed charges" on that price plus the annual operating expenses were equal to or less than the corresponding annual cost with the new plant unit. Any business man will grant the truth of this criterion the moment he understands it. Expressed as a formula it is:

$$Rv + e = RC + E \quad \text{(1)}$$

In which R is the "fixed charge" rate (interest, etc.); v is the depreciated value of the old plant unit whose average annual operating expenses are e; C is the first cost of an equivalent new plant unit and E its average annual operating expenses. From this equation the following is derived:

$$v = C - \frac{e - E}{R} \quad \text{(2)}$$

This is the simplest form of what may be termed the Rational Depreciation Formula, a more general form of which is the Unit Cost Depreciation Formula which we are about to deduce. This formula was first deduced in Gillette's "Handbook of Cost Data."

Although all the data for the accurate application of the unit cost depreciation formula may not always be available, it is important to appreciate that it is the only rational depreciation formula of perfect generality; and that any other depreciation formula that may be used can be justified only on the ground that it gives results approximating those derivable from the use of the unit cost depreciation formula. The authors make no qualification whatsoever in the foregoing statement, and they emphasize it because there still remain many engineers who think that some such age-life formula as the "straight line formula" is quite as logical and fully as general in its application as any other. Yet no advocate of an age-life formula has yet been able to refute the following:

If it cannot be shown that the substitution of a new plant unit (or group of plant units) will decrease average operating expenses, then the value of the old plant unit is as great as the value of a new plant unit.

Recently we had occasion to apply this generalization in the case

of a water works reservoir that was 30 years old. It had suffered no natural depreciation except a small leak which could be repaired for about $100. The reservoir was of permanent construction, and it was adequate in capacity not only for present but for future needs. No larger reservoir would be built if a new one were built to-day. A stand pipe could not be economically substituted for it, and no other suitable reservoir site existed nearer to the city or more desirable because of greater pressure. We held that its age of 30 years had not the slightest bearing upon its depreciated value. Our judgment as to its value would be unaffected were it 300 years old or 3 years old. Our criterion of its value was entirely independent of its age. The criterion was the total annual cost of the most economical substitute for it, and by this test the 30-year-old reservoir, instead of being worth less than a new alternative reservoir, was worth more. This added value we regarded as the value of the reservoir site.

In the following discussion of the unit cost depreciation formula the term "old plant" will be used to designate the existing plant unit or group of units whose depreciated value is to be determined, and the term "new plant" will designate the most economic new plant unit having the same annual output as the old plant unit. Wherever the word "annual" occurs, it is intended to mean "equated annual" or true average annual. Where the word "annual" occurs in reference to the old plant, it relates to the average for the *remaining* years of its life, but where the word "annual" occurs in reference to the new plant, it relates to the average for its *total* economic life. Small letters relate to the old plant, and capital letters relate to the new plant.

Let —

a = Age of old plant in years.
C = First cost of the new plant.
c = First cost of the old plant.
D = Depreciation annuity rate for the *total* natural life.
d = Ditto for *remaining* natural life.
E = Equated annual operating expenses (including taxes) during entire life of the new plant, inclusive of repairs and cost of natural depreciation, but exclusive of functional depreciation annuity.
e = Ditto for old plant during its remaining life.
F = Functional depreciation annuity rate for new plant.
f = Functional depreciation annuity rate for old plant.
K = Total equated annual cost during *entire* life of the new plant.
k = Total equated annual cost during *remaining* life of the old plant.
N = Total life of new plant in years.
n = Remaining life of old plant in years.
R = Interest rate plus functional depreciation rate.
r = Interest rate, including risk insurance and proprietary supervision not included in F, f, E. e.
S = Salvage value of new plant.
s = Salvage value of old plant.
U = Unit cost of product of new plant.
u = Unit cost of product of old plant.
v = Depreciated value of old plant.
Y = Number of units annual product with new plant.
y = Ditto with old plant.

Then we have:

$$U = \frac{K}{Y} = \frac{E + (C\text{-}S)\,F + r\,C}{Y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$u = \frac{k}{y} = \frac{e + (v\text{-}s)\,f + r\,v}{y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The old plant must have a depreciated value, v, such that the unit cost, u, of its product must equal the unit cost, U, of the product of the new plant. Were u more than U, it would be more profitable to buy the new plant. Were u less than U, it would be more profitable to buy the old plant. But a condition of equity exists only when it is as profitable to buy the old plant at the value, v, as to buy the new plant at the cost C. This condition of equity is satisfied when u = U.

Then —

$$\frac{E + (C - S)\,F + r\,C}{Y} = \frac{e + (v - s)\,f + r\,v}{y} \quad \ldots\ldots\ldots (5)$$

$$v = \frac{y}{r + f}\left[\frac{E + (C - S)\,F + r\,C}{Y} - \frac{e - fs}{y}\right] \ldots\ldots (6)$$

Equation (6) is the most general expression of the economic depreciation formula, but it may be reduced to much simpler terms for ordinary use. Usually $Y = y$, and $S = s$, or if these are not exactly equal the quality is so close that v is not appreciably affected by assuming perfect equality. Also it often happens that F and f are equal or nearly so. Assuming these equalities, we have:

$$v = C + \frac{E - e}{r + f} = C - \frac{e - E}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Equation (7) is the economic depreciation formula in a simplified but still very general form. Expressed verbally, Equation (7) is: *Assuming equal gross income, equal annual output, equal salvage value and equal prospective functional life for new and old plant units, the depreciated value of an old plant unit is equal to the cost of a new plant unit of most economic design minus the capitalized difference in their equated annual operating expenses during the prospective economic life.*

It will be noted that the rate of capitalization *(R)* is the sum of the interest rate *(r)* and the functional depreciation rate *(f)* when the operating expenses *(e* and *E)* do not include functional depreciation annuities. This is an important point, and one that is frequently overlooked in capitalizing incomes and expenses.

Formula for Accrued Natural Depreciation: When functional depreciation is non-existent, we have $f = o$, and then the depreciation formula, equation (7), becomes:

$$v = C - \frac{e - E}{r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

In this case C is the cost new of a plant unit of the same size and class as the old unit whose depreciated value is v. E is the equated annual operating expense, including the depreciation annuity required for a sinking fund to redeem the full wearing value $(C - S)$, during N years *total natural* life of the unit; and e is the equated annual operating expense, including the depreciation annuity required for a sinking fund to redeem the remaining wearing value $(v - s)$ during the *remaining natural* life of n years.

If annual operating expenses other than depreciation are M, and are the same for a new as for an old plant unit, we have:

$$E = D\,(C - S) + M. \qquad \text{.........................(9)}$$

$$e = d\,(v - s) + M. \qquad \text{.........................(10)}$$

Substituting in equation (8), and remembering that $s = S$, we have:

$$v = \frac{r\,C - d\,(v - S) + D\,(C - S)}{r} \qquad \text{..............(11)}$$

$$v = S + \frac{D + r}{d + r}\,(C - S). \qquad \text{......................(12)}$$

Equation (12) gives identically the same results as the ordinary sinking fund formula for depreciation, which is:

$$r = S + \left[1 - \frac{(1 + r)^a - 1}{(1 + r)^N - 1}\right](C - S) \qquad \text{........(13)}$$

That Equations (12) and (13) give identical results may be shown by the use of sinking fund tables in the solution of specific numerical examples. In view of the importance of the subject, a strict mathematical proof may be demanded by some engineers. Accordingly it is given herewith.

Proof of Identity of Equations (12) and (13):

$$n = N - a. \qquad \text{.................................(14)}$$

$$D = \frac{r}{(I + r)^N - I} \qquad \text{..............................(15)}$$

$$d = \frac{r}{(I + r)^n - I} = \frac{r}{(I + r)^{N-a} - I} \qquad \text{..........(16)}$$

Substitute these values of D and d in Equation (12).

$$v = S + \left[\frac{\dfrac{r}{(1 + r)^N - 1} + r}{\dfrac{r}{(1 + r)^{N-a} - 1} + r}\right](C - S).$$

$$= S + \left\{ \frac{(1+r)^N \left[(1+r)^{N-a} - 1 \right]}{(1+r)^{N-a} \left[(1+r)^N - 1 \right]} \right\} (C - S) \quad ..(17)$$

Multiplying both numerator and denominator by $(1+r)^{n-a}$ we have:

$$v = S + \left[\frac{(1+r)^N - (1+r)^a}{(1+r)^N - 1)} \right] (C - S)$$

$$= S + \left[1 - \frac{(1+r)^a - 1}{(1+r)^N - 1} \right] (C - S) \quad ....(18)$$

Since Equation (18) is the same as Equation (13), it follows that Equation (12) gives the same value for v as does Equation (13), which was to be proved. Hence the special case, Equation (12), of the rational depreciation formula, Equation (8), is seen to be another form of the sinking fund formula for depreciation. Hence the sinking fund formula is correctly applicable only where *natural* depreciation is involved and only where current repairs are uniform or absent.

Inspections and Tests. In order to apply the "rational depreciation formula," it is usually necessary to inspect the plant units and it is often necessary to test some classes of them. These steps are taken in order to estimate the prospective operating expenses.

Studies of the accounting records may be of considerable aid in determining what the prospective costs of repairs will be by showing the amount, character, expense and dates of past repairs. Thus, a boiler whose flues have been recently renewed will obviously cause less prospective operating expense than one whose flues are old; therefore it will have a higher depreciated value.

Tests of the efficiency of a pump will indicate its fuel consumption as contrasted with a new pump. Inspection of the pump will disclose what parts are worn, and what the probable date of their renewal will be. With these factors known, and with a knowledge of efficiency and maintenance costs of modern pumps, the "rational depreciation formula" can be applied with considerable accuracy. Whereas merely to guess at the depreciated value after an inspection is likely to yield results far from the truth. To apply an "age-life formula" is likely to result in even greater error. This is notably so in the case of buildings, reservoirs and other structures that are practically everlasting if properly maintained.

Criterion for Retiring Obsolete or Inadequate Plant. The general formula for depreciated value, Equation (5), may be used as a criterion for determining whether a plant unit has ceased to be economic and should be retired. The condition for such retirement is that the depreciated value, v, shall be equal to or less than the salvage value, s; for if the depreciated value, v, has reached so low an amount that the plant has no greater value as an economic producing instrument than its salvage value, then it is worth more to its owner as merchandise than as a productive instrument.

Hence if we let $v = s$ and $y = Y$, equation (5) becomes:

$$E + (C - S) F + rC = e + rs \quad \dots\dots\dots\dots\dots\dots (19)$$

When the equality of (19) is destroyed because the left hand member of (19) is less than the right hand member, the old plant should be retired in favor of the new plant.

Depreciated Plant Value Only a Part of Total Value. Plant value is a function of the net earnings derivable from the operation of the plant. By assuming the gross earnings to be constant (that is, not affected by changing the plant), we have deduced a rational formula for ascertaining the depreciated value of a given plant unit. Observe, then, the absurdity of reducing rates of charge so as to yield only normal interest on depreciated value. A company devises a new plant unit of a given class for the purpose of reducing operating expenses. It thereby destroys most of the value of its old plant units of that class. But it does so because of the enhanced value given to its entire property by virtue of increased net earnings. Then comes a rate regulating commission and cuts rates so as to confiscate these increased profits, upon the theory that the commission is concerned with present conditions and present values of *plant only!*

It is asserted that to capitalize profits involves circular reasoning in fixing a rate making value. *But it is entirely overlooked that depreciation due to invention and inadequacy is itself a function of profits.* If there were to be no increased profits as a result of invention and better engineering design of plant, then economic progress would halt and functional depreciation would cease.

Functional depreciation caused by a company itself is irrevocably tied to appreciation of its prospective profits. Those who contend that profits cannot affect rate making value do not understand the full significance of the term value. That this ignorance exists may be shown in many ways. Thus, commissions have used "depreciated values" as a base for rates, although most of the depreciation is functional and caused by the company's own efforts; and functional depreciation is dependent on profits.

Most appraisers assert that they do not re-engineer the plant they are appraising. They estimate the cost of reproducing the "identical plant" and therefrom deduct accrued depreciation. But when they deduct depreciation, most of it is functional depreciation, and they seemingly fail to realize that they are thus re-engineering the plant.

From the foregoing discussion it should be evident that only *natural* depreciation should be deducted if the "identical plant" theory of appraisal is adopted. If functional depreciation is deducted, then assuredly functional appreciation should be given due consideration. If, for example, a railway has built a cut-off line and abandoned an old line, it has done so because the functional appreciation due to the cut-off is greater than the functional depreciation due to abandoning the old line. Hence, if the cost of the old line is to be deducted from the total property value, an even greater sum should be added to cover the appreciation in value

consequent upon the building of a cut-off line that reduces operating expenses. In short, commercial values cannot be disregarded in an appraisal if there is to be a rational result.

Identical Plant Theory. Most engineers seem to think that "cost of reproduction" implies the reproduction of an *identical* plant, but then when they come to consideration of depreciated value they "cross their wires," for they deduct therefrom estimated accrued depreciation due to "inadequacy," "obsolescence resulting from invention," etc. When they do that they fail to see that no longer are they sticking to their "identical plant" theory, but are actually setting up as a criterion another plant — the most economic substitute plant. There is no method of rationally estimated accrued depreciation of all kinds save by comparison with the most economic substitute. But in appraising an entire property this method carries us logically into a consideration of the cost of building up the attached business *in the face of competition with the existing plant*, and not upon the hypothesis that the existing plant does not exist.

Life Tables of Plant Units. For years many engineers and others have been accustomed to use age-life formulas ("straight line" and "sinking fund") for calculating accrued depreciation, and have published plant life tables, sometimes called mortality tables. These life tables are commonly said to give "average lives," but the authors have yet to see accompanying explanations of how "averages" were determined. Usually such tables do not even indicate whether the life is natural or functional or composite, to say nothing of whether the functional life is brought to a close because of economic inadequacy of size of plant unit or because of the invention of a more efficient type of plant unit. Hence it is not putting the matter too strongly to say that practically all published data as to "average lives" of plant units are no better than rough approximations which are often exceedingly deceptive.

In Table I, we have prepared from original and published data a table of estimated lives, in years, of plant units, giving the different units alphabetically arranged, the estimated life in years and the authority quoted. As noted above, most of these lives are functional or composite and therefore cannot be used in figuring depreciated values by the straight line or sinking fund methods. As a basis for calculating depreciation annuities, however, this table will be found very valuable.

KEY TO AUTHORITIES IN TABLE I

A — Wisconsin R. R. Commission.

B — St. Louis Public Service Commission, Union Electric Light & Power Co.

C — Traction Valuation Commission, Chicago Consolidated Traction Co.

D — B. J. Arnold — Appraisal of the Coney Island & Brooklyn Railroad, Feb. 1, 1909.

E — Leonard Metcalf, Transactions American Society Civil Engineers, 1909, p. 24 Vol. LXIV.
F — Henry L. Gray.
G — Arbitrators, Street Lighting Controversy, Atlanta, Ga., 1899.
H — Nathan Hayward, The Bell Telephone Co. of Pennsylvania, Aug. 31, 1912.
I — H. P. Gillette, Everett Railway & Water Co., Jan. 29, 1912.
J — H. P. Gillette, Washington Ry. Appraisal.
K — Henry Floy, 3rd Ave. Case N. Y. City.
L — Prof. M. E. Cooley, Milwaukee 3c case.
M — Beegs, Milwaukee 3c case.
N — M. G. Starret, Milwaukee 3c case.
O — W. D. Pence, Milwaukee 3c case.
P — Union Traction Co., Case Chicago and Union Traction Co., Stone & Webster.
Q — B. J. Arnold, Chicago Appraisals 4 cases.
R — Marwick, Mitchell & Co., Appraisal of a large street railway system, Foster, p. 199.
S — Chicago Traction Commission.
T — Milwaukee Electric Railway & Light Co.
U — George W. Cravens, Industrial Power Plants.
V — Gillette's Handbook of Cost Data.

TABLE I. ESTIMATED LIVES IN YEARS OF PLANT UNITS

Kind of plant	Estimated life years	Authority
Aerial lines	20	B
Arc lamps	6.7	G
" "	12.5	B
" "	15	A
Batteries, storage	10	T
" "	10–20	U
" "	15	A
" "	15–20	P
" "	20	B
" "	20	K
" "	33.3	R
Belting	20	A
Benches (gas plant)	25	A
Bins, storage	10–33.3	Q
Boilers	10	D
"	10–28.6	S
"	11.75–15	O
"	12–16	E
"	13.3	T
"	15–20	P
"	22.2	R
"	25–28.6	C
"	28.6	Q
"	30–40	U
Boilers, fire tube	10	G
Boilers, fire tube	15	B
Boilers, fire tube, elect. light plants	15–30	A
Boilers, fire tube, waterworks	20–25	A
Boilers, water tube	20	K
Boilers, water tube, elect. light plant	20	A
Boilers, water tube, waterworks	20–25	A
Brakes, air	20	A
Bridges	40	R

Kind of plant	Estimated life years	Authority
Bridges, Howe truss	16.7	J
Breechings, steel	10	Q
Breeching & connections	10–28.6	C
Blowers, centrifugal (gas plant)	15	A
Buildings	33.3	T
"	40	R
"	50–100	U
Buildings, brick	25–50	A
Buildings, brick	66.6	C
Buildings, carhouses	33.3	I
Buildings, car barns	50	A
Buildings, coal sheds & stables, frame	20–25	A
Buildings, dwellings, frame	35	A
Buildings, frame	20–50	E
Buildings, frame	50	G
Buildings, gas retort houses, brick	30	A
Buildings, grain elevators	33.3	J
Buildings, masonry	40–50	E
Buildings, misc.	33.3	I, J
Buildings, office 1st class stone and brick	75	A
Buildings, power plant	33.3	I
Buildings, power stations	50	A
Buildings, railroad transportation dept.	33.3	J
Buildings, roundhouses	33.3	J
Buildings, shops	33.3	I, J
Buildings, shops, 2nd class	50	A
Buildings, snow sheds	25	J
Buildings, stations, fuel and water	33.3	J
Buildings, stations and waiting rooms	33.3	I
Buildings, sub-station	33.3	I
Buildings, telephone	24	H
Bulkheading	10	J
Cables	15–25	U
Cables	20	T
Cables	50	S
Cable, aerial exchange	12	H
Cable, aerial exchange loading coils	20	H
Cable, aerial exchange terminal	10	H
Cable, aerial lead covered	12	A
Cable, aerial lead covered	15	A
Cable, aerial toll	12	H
Cable, feeders	25	O
Cable, feeders	66.6	Q
Cables, feeders overhead	33.3	R
Cables, feeder, underground	25	R
Cable, house	13	H
Cable, house terminals	10	H
Cable, submarine	9	H
Cable, underground (u. g.)	16.6	I
Cable, u. g. exchange main	20	H
Cable, u. g. exchange, subsidiary	13	H
Cable, u. g. exchange loading coils	20	H
Cable, u. g. exchange terminals	10	H
Cables, u. g. high tension	20	K
Cable, u. g., lead covered	20	A
Cables, u. g., lead covered	20	B
Cables, u. g., lead covered	25	A
Cable, u. g. toll	25	H
Cable, u. g. toll loading coils	20	H
Cable, u. g. terminals	10	H
Cars, see Rolling Stock.		
Chimney	33.3	C
Chimney, steel	10	D

Kind of plant	Estimated life years	Authority
Chimney, steel	14.3	Q
Chimney, brick	33.3	Q
Coal & ash handling machinery, see Machinery.		
Compressors, air	20–25	C
Concentrators ammonia (gas plant)	15	A
Condensers	10	G
"	15	B
"	20	A, D, K
"	25	C
Condensers (gas plant)	30	A
Conduits	50	A, B
Conduits	100	K
Conduits (includes manholes)	50	R
Conduit, u. g.	16.6	I
Conduit, u. g., exchange, main	50	H
Conduit, u. g. exchange, subsidiary	15	H
Conduit, u. g. toll	50	H
Conveyors	22.2	R
Cranes	50	Q
Cribbing	10	J
Cross-Arms	8–12	A
Crossings, R. R.	12.5	I
Culverts, log or timber	16.7	J
Dams	33.3 & 50	I
Distribution system, elec. ry.	11.75	M
" " " "	12.5	L
" " " "	14.25	N
" " " "	33.3	I
Docks	33.3	J
Drains, box	16.7	J
Economizers	10–20	Q
Engines	22.2	R
Engines, gas	15	A
Engines, steam	10–33.3	S
" "	13.3–20	D
" "	15–20	O, P
" "	15–25	E
" "	20	K, T
" "	20–33.3	B, Q
" "	20–40	U
Engines, steam, high speed	15	A, B
Engines, steam, high speed	20	G
Engines, steam, slow speed	20	A
Equipment	8	I
Equipment, electrical	11.75	M
Equipment, shop	10	I
" "	10–25	U
" "	10–33.3	S
" "	13.3	T
Equipment, power plant	20	I
Exhausters (gas plant)	25	A
Extractors, tar, P. & A. (gas plant)	40	A
Feeders, see Cable.		
Fences	14.3	J
Fences	20	R
Fences, snow	10	R
Foundations, machinery, same as life of apparatus supported	....	C, K
Foundations, machinery	16.6	Q
Furniture	7	A
Furniture and fixtures	12.5	L
Furniture and fixtures	20	I, N. R
Gas connections, c.i. (within the plant)	50	A
Gas (water) machines complete	30	A

Kind of plant	Estimated life years	Authority
Gas mains, cast iron 3 ins. and 4 ins.	50	A
Gas mains, c.i., 6 ins. and larger....	75	A
Gas mains, wrought iron and steel under 3 ins.	20	A
Gas mains, w.i. and steel over 3 ins.	30	A
Gas services	20	A
Generators	12.5–33.3	C
"	15–20	P
"	20	D. K, O, Q
Generator, belted	10–20	S
" "	13.3	T
" "	15	U
Generators, direct connected........	13.3	T
" " "	20	S
" " "	25	U
Generators, modern type	20	A
Generators, obsolete type	15	A
Generators, steam-turbo	15	B
" " "	20	A
" " "	10	G
Governors, gas (consumer's)	25	A
Governors (gas plant)	5	A
Heaters	16.7–25	C
Heaters	22.2	R
Heaters	33.3	Q
Heaters, feed water, closed	30	A
Heaters, feed water, open	30	A
Holders (gas plant)	50	A
Horses and wagons, see teams and vehicles.		
Hydrants	40–50	E
Hydrants, connections	6.6	I
Locomotives	28–31	V
Machinery, coal & ash handling....	5	O
" " " " "	10	A
" " " " "	14.3	Q, C
" " " " "	15–20	P
" " " " "	20	K
Machinery, electrical	20–30	E
Machinery, fuel oil handling	25	C
Machinery, shop	10	J
" "	10–30	O
" "	12.5	L
" "	14.25	N
" "	20	R
" "	20–50	P
Meters, electric service	12.5	B
Meters, electric service	15	I, A
Meters, electric switchboard	20	A
Meters, gas (consumers)	25	A
Meter cases, station (gas plant).....	50	A
Meter drums, station (gas plant)...	20	A
Meters, water	20	I
Meters, water	20–30	E
Motors	10–20	S
"	15–25	U
"	20	T
Motors, railway	10	G
" "	20	A, K
" "	30	C
" " See rolling stock, elect. equip.		
Overhead equip. (elect. ry.)	5	Q
Overhead spans, complete	20	R
Overhead, special work	12.5	R

Kind of plant	Estimated life years	Authority
Overhead, systems	10–20	U
Overhead, systems	13.3	T
Paving	2	K
"	10	L
"	10–25	P
"	11.7	M
"	12.5	N
"	20	I
Paving	20	K
Paving, block	40	R
Paving, brick	22.2	R
Paving, tracks in car houses	28.6	R
Pipe, black iron	10	I
Pipe, cast iron small diam.	20–40	E
Pipe, c. i. large diam.	50–75	E
Pipe, galv. iron	10	I
Pipe, Matheson	30	I
Pipe, screw flange	20	I
Pipe-steel	25–50	E
Pipe, wood stave	20–30	E
Pipe, wood	25	I
Pipe, also see gas mains.		
Pipe, fittings	20	I
Piping and covering	5	K
" " "	15	B
" " "	15–20	P
" " "	16.6	D
" " "	20	A, O
" " "	22.2–25	C
" " "	28.6	Q
Piping, steam	13.3	T
" "	28.6	S
" "	30–40	U
Poles, iron	20	P
" "	40	A, O, Q
" "	50	R
Poles, steel	50	K
Poles, telephone	12–15	A
Poles, wood	12–15	O
" "	14.3	R
Poles, wood in concrete	20	A
Poles, wood in earth	12–18.2	A
Poles, wooden	10	G
Pole lines, exchange (telephone)	10.5	H
Pole lines, tool (telephone)	16	H
Power plant	12.5	L
" "	20	N
" "	50	Q
Power plant and wire telephone	8	A
Pumps	20	C, D, K, Q
"	20–25	I
Pumps, small steam	15	A, B
" " "	20	G
Pumps and auxiliary machinery	20–30	E
Pumps and auxiliaries	22.2	R
Purifiers, modern (gas plant)	50	A
Rental equipment, elec.	15	I
Reservoirs	33.3–50	I
Reservoirs (except where subject to heavy deposit of silt)	50–100	E
Rolling stock, cars electric	13.3–16.7	T
Rolling stock, cars (including all equipment)	20	R
Rolling stock, bodies closed cars	20	C
Rolling stock, cars, bodies open cars	25	C

Kind of plant	Estimated life years	Authority
Rolling stock, bodies open trailer....	25	C
Rolling stock, cars, bodies, trucks...	12.5	L
" " " " " ...	15	M
" " " " " ...	15–20	O
" " " " " ...	16.7	N
" " " " " ...	20	P
Rollng stock, car bodies and equip...	15	A
Rolling stock, elect. equip.	3.3–4–8.5	Q
Rolling stock, equip. electrical......	11.75–15	P
Rolling stock, trucks	20	K
Rolling stock, trucks	30	C
Rolling stock, utility equipment	20	R
Rolling stock, cars, wooden freight..	27.5	V
Rotary converters	20	T
Rotary converters	20–25	U
Rotaries	22.2	R
Service connection, elect.	28.5	I
Service connections, water	20	I
Scrubbers (gas plant)	30	A
Signal apparatus	10	R
Signal apparatus, interlocking	20	I
Stacks, see chimneys.		
Standpipe	10	I
Standpipes	25–40	E
Stokers	4	Q
Stokers, moving parts	5	C
Stokers, fixed parts	20	C
Switchboards	15–20	P
"	20	T
"	20–50	U
"	22.2	R
"	50	O, Q, S
Switchboard and wiring	33.3	C
" " "	16.7	D
" " "	20	K
Switchboard and wiring, modern type	20	A
Switchboard and wiring, obsolete type	15	A
Tanks storage ammonia, wrought iron or steel	15	A
Teams and vehicles	5–8	I
" " "	10	L, R
" " "	20	N
Telegraph (signal)	10	R
Telephone equipment, central office..	8.25	H
Telephone equipment, sub-station (except installations but including sub-station, central office equip., public brand exchanges booths and special fittings, sub-license station apparatus)......	9	H
Telephone central office equipment including distributing frame....	10	A
Telephone and telegraph lines.......	20	I
Telephone, subscribers sets	10	A
Tools	5	I
"	7	A
Tools, roadway	5	I
Tools, shop	10	J, R
" "	12.5	L
" "	14.25	N
" "	10–30	O
" "	20–50	P
Track-ballast	33.3	I
Track, bonds	20	A, C
Track, fastenings and joints	33.3	I

Kind of plant	Estimated life years	Authority
Track fastenings	40	J
Track, main	11.7	M
" "	12.5	L, N
" "	12.9–13.9	P
" "	13.3	T
Track, straight	18.2	A
Track-rails	33.3	I
Track-rails	40	J
Track-rails in city streets	22.2	R
Track-rails in country roads	28.6	R
Track-rails in private r. of w.	28.6	R
Track, rail joints	20	C
Track, special work	8.5	T
" " "	8–14–25	O
" " "	10	Q
" " "	11.1	R
" " "	11.75	A
" " "	12.9–13–9	P
" " "	25	I
Track, substructure:		
City streets	22.2	R
Country roads	14.3	R
Private right of way	10	R
Track, ties	8	J
Track, ties	13.3	I
Track, ties	20	C
Transformers	20	T
"	20–33.3	U
"	22.2	R
Transformers, station service	15	B
" " "	15–20	A
" " "	20	I
Transmission line material	33.3	I
" " "	50	R
Turbo-generators	16.7	R
Turbines, steam	20	A
" "	15	B
" "	20	T
" "	20–40	U
Turbines, water	30	A
Valves	16.6	I
Valves, gate (water)	40–50	E
Washers, cast iron (gas plant)	40	A
Water supply lines	25–33.3	I
Wells, tar and ammonia (gas plant)	50	A
Wharves	33.3	J
Wires	15–25	U
"	20	T
"	50	S
Wiring	7.1–10	P
Wire, copper	20	A
Wire, guard	10	R
Wire, guard	8–15	A
Wire, telephone aerial exchange bare copper	14	H
Wire, telephone aerial exchange bare iron	8.5	H
Wire, telephone aerial exchange insulated (including drop wires)	6.5	H
Wire, telephone aerial toll, copper	30	H
Wire, telephone aerial toll, iron	15	H
Wires, telephone interior block	8	H
Wire, trolley #0 — 1 min. headway	2	A
Wire, trolley #00 — 1 min. headway	2.5	A
Wire, trolley #000 — 1 min. headway	3	A

Kind of plant	Estimated life years	Authority
Wire, trolley	20	R
Wire, weatherproof	13.3	G
Wire, weatherproof	16	A
Wire, weatherproof iron	15	A

There are many published tables of the *average* prospective lives of different kinds of plant units. Engineers have almost universally misused these tables, for they have considered that an *average prospective* life could be used in calculating the *individual accrued loss of value* of a given plant unit. Under but one condition, or rather set of conditions, is it correct to use life tables in estimating accrued depreciation, namely: (1) The life of the *particular* plant unit under investigation must correspond to the life of the *average* life given in the table. This is never true, save by chance, where functional depreciation is involved. (2) There must be no appreciable difference in the lives of the *parts* that go to make up the whole of each plant unit. This is seldom true save where there are no parts that are renewed before the renewal of the whole plant unit.

To put these statements in concrete form, it may be approximately correct to say that a given wooden pole, or a railway tie, or a horse will have a life the same as that given in a table of average lives of such things. But it may be, and usually is, wholly erroneous to assume that a given pump or a given water main will have a life the same as that given in an average prospective life table. The natural life of a wooden pole, or cross-tie, or horse, ordinarily does not differ very materially even in different parts of the country; whereas the functional life of an individual pump or a given water pipe may, and usually does, depart greatly from the averages given in life tables.

In this connection attention should be called to the fact that the lives of water works units, as given in published life tables, are nearly all functional lives. Thus, reservoirs are assigned a life of 50 to 100 years. What does this mean? That a reservoir will be rusted, decayed or abraded to such an extent at the end of 50 to 100 years that it will be no longer serviceable? Not at all. It means that some engineer has come to the conclusion that the *average* reservoir has been outgrown and abandoned at the end of 50 to 100 years, and that he infers that the *average* existing reservoirs will, in the future, be replaced in 50 to 100 years. Now he may be entirely right, and, if so, the owner of every reservoir may wisely provide enough out of earnings to amortize the investment in his reservoir within 50 to 100 years. But this is not tantamount to saying that a given 25-year-old reservoir has lost one-half to one-quarter its life, as many engineers have erroneously inferred.

In logic one of the fundamental principles is this: *Conclusions of fact respecting averages of many individual cases are correctly applicable only where many cases of the same sort are involved.*

Thus, it may be a fact that the average child has an expectancy

of 35 years' life at birth. It may also be a fact that the average man 35 years old has an expectancy of 25 years' remaining life. But neither of these facts may be at all applicable in a given individual case, unless that individual is to be treated as one of a large group of similar individuals, as is done by insurance companies.

There are reservoirs hundreds of years old and in service. The same is true of aqueducts, pipes, buildings, etc. The *natural* life of such things is often so great as to be beyond determination. Even machinery of the heavier sorts often has a natural life much greater than is given in life tables relating to machinery. Thus, pumps are commonly assigned a life of 20 to 30 years, but that this is assumed to be an average functional life and not a natural life is evidenced by such facts as the existence of pumps 50 years old and still in active service. Stevenson's second locomotive is still in use in an English colliery after a century of service.

In the recent case of the Denver Union Water Co. versus City of Denver, an eminent engineer testified that the pumps in use by the company have an average age of 27 years, and he assigned a total probable life of 41 years to the pumps in spite of the fact that no published life table gives more than 30 years' life for pumps. In the same case he assigned a probable life of 41 to 47 years to the wooden pipe in Denver, although the actual age of some of the pipe was nearly as old as the 30 years' extreme life given in published life tables. To this we may add our own observation in two water works appraisal cases where much of the wooden stave pipe was nearly a quarter of a century old. Practically all of it was still in perfect condition as to the wood and the bands were but slightly rusted.

In the Denver case a life of 23 years was assigned to boilers by an engineer representing the company, and it was stated that many of the boilers were more than 16 years old, doing good service and approved by boiler insurance companies.

The same engineer in the Denver case assigned to cast iron pipe the following lives:

16-in. and larger	94 years
10 to 15-in.	72 years
6 to 8-in.	56 years
3 to 4-in.	41 years

In this connection it is of interest to cite the fact that 6-in. cast iron pipe laid on Locust from 7th to 8th streets, Philadelphia, was recently removed after having been in service 88 years. The pipe had been cast on its side, for it varied from .5 to .3125 in. thick. Its interior was tuberculated, but the iron showed no deterioration. The pipe might have remained in use indefinitely had it not been necessary to make way for a sewer. This and other examples show that the *natural* life of cast iron pipe is so great as never to have been recorded.

Since most plant lives depend largely upon the rate of growth of the towns or cities, it follows that an average life for England

would not be an average life for America. An average for Maine would not be an average for California. An average for villages would not be an average for cities. And so on indefinitely. A halt should be called on the indiscriminate use of "average lives," gathered nobody says how and often by whom nobody says, nor where nor when. Such data have been passed from author to author, until frequently their age seems to entitle them to the veneration that naturally associates itself with antiquity. But, when we question most of these ancient data on their reason for existence, their only answer is: "We are."

Nearly all property that has been appraised for public utility commissions has been assigned a depreciated value far below its true depreciated value. As an illustration, let us take bare copper wire, which is commonly assigned a "life" of 15 to 20 years in telephone or electric transmission service. The fact is that the natural life of such wire is so great that no man has ever recorded it. The "life" of 15 to 20 years, therefore, is purely a functional life, dependent upon economic inadequacy and the like. If, therefore, a given lot of old copper wire is serving a purpose as economically as if it were new, it cannot be said to have depreciated functionally. And as the natural life of copper wire may be hundreds of years, the old wire has not depreciated to any measurable degree naturally. In brief, under these conditions, it has not depreciated at all unless the price of copper has dropped. Yet, it is a common thing to see an estimate of depreciated value of copper wire put at 65 to 75 per cent its cost new simply because it is a few years old. The same error is to be seen in the case of depreciated values assigned to buildings, to rolling stock, to machinery, and, indeed, to nearly every class of plant units. *An average functional life is not only treated precisely as if it were a natural life, but is applied to particular cases where no average is applicable at all.*

The life of water works pumps is said to average 20 years. Many engineers and nearly all laymen think that this means that the average pump *wears* out in 20 years, but even where they know better they make the mistake of substituting the 20-year functional life in a sinking-fund formula that is not applicable except where natural life is involved.

Where an average life given in a life table is clearly a *natural* life, such, for example, as a 10-year life of a railway tie, no error should arise from its use in any correct formula, provided the conditions in the case in hand correspond to those stated or implied in the life table. Where the given average life is *functional,* great care must be exercised in its use; a functional life can not be used at all in a straight line or sinking fund formula for estimated accrued depreciation, for reasons above given; but a functional life can be used in estimating a depreciation annuity to provide a depreciation fund, provided the best evidence points toward a probably equal life for the given plant unit.

Looking into the future, we must obviously be guided by data gathered in the past. If, for example, the history of telephone development has shown that during the past 30 years, the average

functional life of a switch board has been 10 years, and if there are no signs of decreased activity in both the growth of telephone business and of improvements in switch board design, then we are justified in using the 10 year life in providing a depreciation annuity for switch boards. We may therefore properly use this 10-year life in the unit cost depreciation formula, in calculating the depreciated value of a particular switchboard in a city where the telephone business is growing at the general average rate. But it would be illogical to use this 10-year life in a "straight line depreciation formula," for the fact that a given switchboard is 6 years old does not necessarily signify that 60 per cent. of its economic life has departed. What part of its economic life has departed is ascertainable only by the application of the unit cost depreciation formula, using perhaps its simplest form (page 100).

In the life tables, Table I, most of these lives are very unsatisfactory because the data upon which they rest were not published. For the most part it is evident that the lives are functional lives, and are presumed to be "averages" for American localities; but we seriously question whether, in many cases, they are ordinarily applicable outside the locality to which they refer. Indeed we go further and question the applicability of some of these data even in the locality in which they refer.

General experience, up to the present, indicates that few heavy machines of any kind have remained in use longer than 20 to 30 years. American locomotives, for example, have had an average life of about 25 years, but that this short life is due wholly to functional depreciation is proved by such facts as that the second locomotive built by Stevenson is still in use in England, although it is about 100 years old. The functional depreciation of American locomotives has been mainly due to inadequacy. Growth of traffic has made heavier locomotives more economic. But with the growing weight of locomotives, and rolling stock generally, has come the necessity of using heavier rails and heavier steel bridges, so that rails and steel bridges have depreciated functionally at about the same rate as the functional depreciation of locomotives. It is always necessary, therefore, to consider the effect of functional depreciation of one class of plant units upon other classes of plant units. If rails of a street railway depreciate functionally because heavier cars have become economically necessary, pavement between the rails will also have depreciated functionally.

In this way there is often a long chain of functional depreciation of different plant units that are inter-dependent.

Composite Life. We have already discussed the calculation of the "weighted average age" of plant units of a given class. The "weighted average" or composite life of all classes of plant units in a given plant may be calculated as in Table II from a paper by Halford Erickson, late chairman of the Wisconsin Railroad Commission.

This table gives an average composite life of 17.15 years for the plant units of an electric plant, but without knowing what were defined as plant units this average life lacks definiteness. It is to

TABLE II. COMPOSITE LIFE OF ELECTRIC LIGHTING AND POWER PLANT

Class	Life	Cost new, less scrap	Annual per cent. of depreciation	Annual fund required to cover depreciation
A	5	$ 210	20.00	$ 42
B	8	7,110	12.50	889
C	10	17,208	10.00	1,721
D	12	26,272	8.33	2,188
E	15	131,550	6.67	8,774
F	16	32,258	6.25	2,016
G	20	104,097	5.00	5,205
H	25	36,116	4.00	1,445
I	50	14,337	2.00	287
J	60	1,165	1.67	19
K	75	21,920	1.33	292
		$392,243		$22,878

$$\text{Average life} = \frac{392,243}{22,878} = 17.15 \text{ years.}$$

be presumed that each pole, each wire, each transformer, each building, each generator, each boiler, each steam pipe, etc., was regarded as a plant unit; and that each part of a transformer, building, generator, boiler, etc., was not regarded as a plant unit. This average life of 17.15 years would give an average renewal of nearly 6 per cent. year, according to the straight line formulas, which would not include repairs to parts of plant units.

It should be noted that a composite life of this kind can not be accurately used in a sinking fund formula.

The authors have found that in a large number of electric light and power plants, the upkeep cost (repairs and depreciation) has averaged about 8% per annum over long periods of years, using the straight line formula with the plant investment as the base. Of this 8%, about one-quarter was classified as renewals of parts of plant units or repairs, the rest being renewals of entire plant units (poles, wires, etc.).

Where a large part of the distribution system is underground, the composite life is longer than otherwise. Similarly steel towers lengthen the life of the transmission system. For telephone plants the average annual repairs and renewals have been about 11 per cent. of the investment, according to the records analyzed by the authors; and of this 11% nearly one-half was classified as annual repairs and the remainder as annual depreciation. But it is obvious that without a detailed statement of what were regarded as plant units, this statement of the segregation between repairs (or renewals of parts) and depreciation (or renewals of entire plant units) has little significance.

Useful Life of Reciprocating Engines, Generators and Turbo-Generators. Tables III and IV submitted as evidence in a recent "rate case," indicate clearly the great weight of functional depreciation in determining the length of useful life. In a majority of cases the "useful life" given is the result of obsolescence or in-

adequacy rather than the result of mechanical wear or "natural" depreciation.

TABLE III. USEFUL LIFE OF RECIPROCATING ENGINES AND GENERATORS

	Type of equipment				Time of service		
	Reciprocating engines		Generators				
Company	No.	Size in h.p.	No.	Size in kw.	Started	Closed	Useful life years
1.	1	Corliss			1906	1911	4½
2.	1	150	2	45	1891	1907	16
	2	200	4	65	1891	1907	16
	1	150	2	50	1893	1909	16
	3	225	6	75	1893	1909	16
	1	1250	2	400	1894	1915	21
	4	600	8	200	1894	1915	21
	5	1200	10	400	1895	1915	20
	1	3500	1	2500	1901	1915	14
	1	Corliss	2	1000	1902	1915	13
	1	5000	1	3500	1902	1915	13
	1	2500	1	1800	1903	1915	12
	4	200	8	80	1888	1894	6
3.	High speed		Edison d. c.		1887	1893	6
	Compound		a. c. single phase		1893	1905	12
4.			a. c.		1890	1907	16
	5 Allis Chalmers				1904	1915	11
5.	Cross Comp.				1891	1905	14

Average life, 34 reciprocating engines, 14 years.
Average life, 50 generators, 16 years.

TABLE IV. USEFUL LIFE OF TURBO-GENERATORS

		Time of service		
Company	Capacity of equipment in kws.	Started	Closed	Useful life years
6.	1–4,000	1904	1912	8
	1–4,000	1904	1912	8
	1–4,000	1905	1911	6
	1–4,000	1905	1911	6
	1–4,000	1906	1912	6
7.	2–5,000	1903	1909	6
	1–5,000	1904	1909	5
	1–7,500	1904	1909	5
8.	1–1,500	1905	1914	9
9.	2–2,000	1905	1910	5
	4–5,000	1906	1911	4

Average life, 16 turbines, 6 years.

Following is the key to names of companies given in tables III and IV, also the reasons for retiring the various units.

Company No.	Name.	Remarks
1.	Nevada California Power Co.	Equipment replaced by turbine plant, larger unit.
2.	Commonwealth Edison Co. 27th Street, North Clark Street, Harrison St., Adams St. stations.	Entire plants abandoned.
3.	Consumers Power Co. Jackson station	Replaced by a. c. single phase Curtis turbine.

Company No.	Name.	Remarks.
4.	Union Electric Light & Power Co... 10th, 19th and 20th St. stations.	Entire plants abandoned, obsolete.
5.	Indianapolis Light & Heat Co..... Kentucky Ave. station.	Obsolete, but used for steam heating.
6.	Detroit Edison Co., Delroy station..	Entire plant abandoned.
7.	Commonwealth Edison Co.......... Fish Street station.	Replaced by large unit of same type.
8.	Consumers Power Co. .... Jackson station.	Replaced by 7,500 kw. turbine.
9.	Union Electric Light & Power Co.... Ashley Street station.	Replaced by larger units.

An Example of the Determination of Repair and Depreciation Costs of an Electric Company. The following is an abstract of a report by Halbert P. Gillette to the Southern California Edison Co., which report was one of the exhibits in a condemnation case instituted by Los Angeles, and heard by the California Railroad Commission in 1915–16.

Before entering upon the discussion and analysis of what the up-keep expenditures of this property (electric dept., So. Cal. Edison Co.) have been during the 19 years' history of the Company, it may be well to state that any thorough study of the reasonableness of a given depreciation annuity necessarily involves a study of the current maintenance expenses. So far as I know, there is in existence no accounting system in which thoroughly exact definitions have been given as to the meaning of the terms "repairs," "renewals" and "depreciation." Hence it follows that accountants using their own judgment as to these terms may at one time charge to current repairs items that at another time they might charge to depreciation.

Repairs, or current maintenance, may be said to provide for renewals of *parts* of a "plant unit," whereas the depreciation annuity provides for the renewals of *entire* plant units. The distinction rests upon the definition of what constitutes a plant unit. To illustrate: One person may regard a bare pole as being a plant unit; another person may regard a pole with its crossarms and all other attachments as being a plant unit; still another person may regard the entire pole line, including wires, as being a plant unit. Obviously what one of these persons would call repairs, another might call a charge to depreciation reserve.

Since it is impracticable to ascertain now exactly what was in the minds of the accountants who made the distinction between repairs and renewals in the past years, we are forced to combine all up-keep expenditures for each year in the past, and we may call this combination of repairs and renewals "up-keep expenditure." We may then ascertain what this total up-keep expenditure has averaged annually and what percentage that average has been of the average investment in depreciable plant.

To this should be added, of course, the accrued depreciation in the plant for which money has not yet been paid out, although it may be in a depreciation fund.

In a very thorough study of up-keep expenditures of the past, it is desirable to investigate charges to capital account that should have been made to maintenance. Also it is desirable to examine the surplus, and the profit and loss accounts to ascertain whether any depreciation charges have been made through these accounts. Likewise, any property sold by the Company at a loss should be regarded as depreciation. Any property abandoned and not charged off the capital account, together with any special fire or storm losses not similarly charged off, should be ascertained, for they are strictly speaking depreciation charges and may not appear either in the operating expenses or in the depreciation reserve accounts. Similarly suspense accounts and all special accounts in which "up-keep" may be found, should be investigated.

Column C of Table V shows what has been charged to maintenance and repairs annually for each year since the Company began operation. Column D shows what has been paid out for renewals inclusive of moneys paid from the depreciation reserve fund. Column E shows the total of these two columns by years. The grand total for the 19 years is $3,295,067, or an average of $173,425 per year for the 19 years. This is the actual expenditure

TABLE V

Maintenance, Repairs, Renewals and Depreciation by Years, and Average for Straight Line Formula, Local and General Property, Electrical Department of Southern California Edison Company.

A Year ending Dec. 31	B Average depreciable property	C Maintenance and repairs	D Renewals	E Total maintenance, repairs and renewals C plus D
1896	$ 31,733	......	......	0
1897	98,228	$ 128	......	128
1898	244,037	1,562	......	1,562
1899	671,785	2,209	......	2,209
1900	1,340,681	10,830	......	10,830
1901	1,463,940	12,698	$ 29,707	42,405
1902	1,849,552	30,672	......	30,672
1903	2,719,740	78,883	......	78,883
1904	4,273,220	70,489	......	70,489
1905	5,544,388	76,586	231,131	307,717
1906	6,702,214	78,325	145,589	223,914
1907	9,697,771	73,573	89,694	163,267
1908	12,166,861	77,984	7,197	85,181
1909	12,507,528	90,449	191,272	281,721
1910	13,120,211	235,105	38,778	273,883
1911	14,273,440	204,259	112,972	317,231
1912	16,339,749	293,950	121,508	415,458
1913	18,548,775	281,737	147,526	429,263
1914	21,182,310	280,112	280,152	560,264
Total	$142,776,163	$1,899,551	$1,395,526	$3,295,067

$7,514,535 — Average for 19 years $173,425

Average percentage of repairs and renewals to plant is $173,425 ÷ $7,514,535 = ... 2.307%

Adding accrued depreciation $3,843,000 * (= 17.244% of $22,286,000 as of Dec. 31, 1914) which divided by 19 years = ...	202,263
Total average annual repairs, renewals and accrued depreciation	$375,688

Average percentage of maintenance, repairs, renewals, and accrued depreciation is $375,688 ÷ $7,514,535 = 5.00% per year, by straight line formula.

* 3,843,000 = 17,244% based on 20% of $10,001,265 local property and 15% of $12,284,993, general property.

ior up-keep, exclusive of any unexpended amounts remaining in the depreciation reserve fund. The average investment in the depreciable plant during these 19 years was $7,514,535, as deduced from Table V. Hence the average expenditure for up-keep has been 2,307% per annum. But in addition the plant has suffered accrued depreciation, which is estimated to have been $3,843,000,[1] as of June 30th, 1915, or an average of $202,263 for 19 years, which, divided by the average investment in that period of $7,514,535 is 2.7% per annum. Adding this 2.7% to the 2.3% expended for up-keep, we have a total of 5% per annum as the average for these 19 years for the entire plant (Local and General combined) based upon the so-called "straight line formula." This, it should be noted, is based upon the history of this company and the only possibility of material error would lie in the estimated accrued depreciation of the plant, which depreciation is 17.24% of the depreciable property as of June 30th, 1914, an amount that seems to be as close to the truth as can be arrived at.

Tables VI and VII give corresponding calculations of the actual up-keep expenditures and accrued depreciation for the Local Property and for the General Property respectively. By the term "General Property" I mean the generating and transmission system, the "Local Property" being the distribution and service systems. It will be noted that in Table VI we find that the average annual cost of up-keep and accrued depreciation has been 6.213% upon the depreciable "Local Property" throughout the 19 years, based upon the straight line formula. It will be noted that in Table VI the corresponding percentage for the "General Property" is 3.746%.

In none of these Tales V, VI and VII is it assumed that a sinking fund was established to care for depreciation. If, however, a 4% compound interest sinking fund had been established in 1896, and if that fund had been built up until June 30, 1915, so that at that time it had equalled the then accrued depreciation of $3,843,000, it would have required a depreciation annuity of 2.258% of the depreciable plant. This fact is deduced in Table VIII which relates to the total plant or Local and General property combined. The method of deduction in that Table is as follows:

[1] The unexpended balance in the depreciation reserve account was $3,675,792, as of June 30th, 1915.

TABLE VI

Maintenance, Repairs, Renewals, and Depreciation by Years, and Average for Straight Line Formula, Local Property. Electrical Department of Southern California Edison Company.

A Year ending Dec. 31	B Average depreciable property	C Maintenance and repairs	D Renewals	E Total C plus D
1896	$ 31,733	......	......	......
1897	98,228	$ 128	......	$ 128
1898	244,036	1,562	......	1,562
1899	474,221	1,263	......	1,263
1900	718,235	4,630	......	4,630
1901	829,310	7,341	$ 29,707	37,048
1902	1,084,337	14,965	......	14,965
1903	1,604,985	48,011	......	48,011
1904	2,484,120	50,709	......	50,709
1905	3,035,768	48,688	186,450	235,138
1906	3,719,531	55,838	122,484	178,322
1907	4,444,197	48,712	74,300	123,012
1908	4,825,894	38,388	221	38,609
1909	4,970,742	45,485	47,088	92,573
1910	5,372,463	136,666	9,464	146,130
1911	5,988,599	133,992	56,609	190,601
1912	6,764,983	185,139	84,150	269,289
1913	8,020,859	162,623	90,149	252,772
1914	9,308,714	166,839	124,765	291,604
Total	$64,020,955	$1,150,979	$825,387	$1,976,366

$3,369,524 — Average for 19 years $104,019

Average percent of property $104,019 ÷ $3,369,524 = ... 3.087%

Adding accrued depreciation on basis of 20% of $10,001,-265, depreciating property as of December 31, 1914, divided by 10 to obtain average, we have 105,296

Average annual repairs, renewals and depreciation $209,315

Average percentage of property is $209,315 ÷ $3,369,524 = 6.213% by straight line formula.

Column B shows the average depreciable property by years. Assuming that 1% depreciation annuity should be set aside annually, we would have the annual amounts shown in Column C. Then compounding these annual amounts at 4%, using the compound interest factor in Column D, we would have the depreciation fund accumulation as shown in Column E, total $1,701,816. But, since the accrued depreciation is $3,843,000, we must divide that by $1,701,816, which gives 2.258% as the proper depreciation annuity. Column F shows the application of this depreciation annuity and Column G shows the final depreciation that would exist in the fund using that annuity and since that calculation totals $3,842,707 we have an almost exact check upon our calculation.

Since it has been shown in Table V that the actual up-keep expenditure has averaged 2.307%, and since we have now shown that a sinking fund annuity of 2.258% would be needed to build a fund equal to the accrued depreciation, the sum of these two, or $4.565%, is the average annual percentage for maintenance, repairs, renewals

and accrued depreciation of the total depreciable electrical property of this Company during the past 19 years.

A similar calculation for the Local Property alone results in 5.668% as the average annual percentage for all up-keep expenditures and accrued depreciation. The corresponding percentage for the General Property alone is 3.399%.

First, let us consider the Local and General Property combined. As shown in Table VIII, the investment in depreciable property averaged $21,182,310 for the year 1914, so if we take 4.565% thereof, we have $971,072 as the sum that up-keep and accrued depreciation would amount to in 1914 based on the experience of the 19 years of this Company's life. Table V shows that, as a matter of fact, the Company spent in 1914, for maintenance and repairs a sum of $280,112 and $280,152 for renewals, or a total expenditure of $560,264, but in that year the Company set aside a depreciation annuity of $700,000, of which $43,000 was for the gas department. Out of this $653,000 was spent the $280,152 for renewals as shown in Table V, leaving a balance of $373,848 that went into the depreciation fund for that year. Hence, if we add together $280,-

TABLE VII

Maintenance, Repairs, Renewals, and Depreciation by Years, and Average for Straight Line Formula, General Property Electrical Department of Southern California Edison Company.

A Year ending Dec. 31	B Average depreciable property	C Maintenance and repairs	D Renewals	E Total C plus D
1899	$ 197,563	$ 946	......	$ 946
1900	622,446	6,200	......	6,200
1901	634,629	5,357	......	5,357
1902	765,215	15,707	......	15,707
1903	1,114,754	30,872	......	30,872
1904	1,789,100	19,781	......	19,781
1905	2,508,619	27,898	$ 44,681	72,579
1906	2,982,682	22,487	9,248	31,735
1907	5,253,573	24,861	922	25,783
1908	7,340,967	39,596	......	39,596
1909	7,536,785	44,964	97,110	142,074
1910	7,747,747	98,439	17,517	115,956
1911	8,284,841	70,267	602	70,869
1912	9,574,765	108,811	26,887	135,698
1913	10,527,915	119,114	23,521	142,635
1914	11,873,596	113,273	154,923	268,196
Total	$78,755,197	$748,573	$375,411	$1,123,984

$4,922,200 — Average for 16 years	$ 70,249
Average percentage of property $70,249 ÷ $4,922,200 = ..	1.42%
Adding accrued depreciation on basis of 15% of $12,284,-993, depreciating property as of December 31st, 1914, equals $1,842,749, which divided by 16 to obtain average gives	115,184
Average annual repairs, renewals and depreciation...	$185,433

Average percentage of property is $185,433 ÷ $4,922,-200 = 3.746% by the straight line formula.

TABLE VIII

Depreciation Fund Annuity for Local and General Property, Combined Electrical Department of the Southern California Edison Company.

A	B	C	D	E	F	G
Year ending Dec. 31	Average depreciable property	Trial depreciation at 1% per year 1% x B	Compound interest factor 4% sinking fund	Trial depreciation fund accumulation C x D	Final depreciation annuity 2.258% x B	Final depreciation fund accumulation F x D
1896	$ 31,733	$ 317	2.03	$ 644	$ 717	$ 1,456
1897	98,228	982	1.95	1,915	2,218	4,325
1898	244,037	2,440	1.87	4,563	5,510	10,304
1899	671,785	6,718	1.80	12,092	15,169	27,304
1900	1,340.681	13,407	1.73	23,194	30,273	52,372
1901	1.463,940	14,639	1.67	24,447	33,056	55,204
1902	1,849,552	18,496	1.60	29,594	41,763	66,821
1903	2,719,740	27,197	1.54	41,883	61,412	94,574
1904	4,273.220	42,732	1.48	63,243	96,489	142,804
1905	5,544,388	55,444	1.42	78,730	125,192	177,773
1906	6,702,214	67,022	1.37	91,820	151,336	207,330
1907	9,697,771	96,978	1.32	128,011	218,976	289,048
1908	12,166.861	121,669	1.27	154,520	274,728	348,905
1909	12.507,528	125,075	1.22	152,592	282.420	344,552
1910	13,120,211	131,202	1.17	153,506	296,254	346,617
1911	14,273,440	142,734	1.12	159,862	322,294	360,969
1912	16,339.749	163,397	1.08	176,469	368,952	398,468
1913	18,548,775	185,488	1.04	192,908	418,831	435,584
1914	21,182,310	211,823	1.00	211,823	478,297	478,297
	$142,776,163			$1,701,816	$3,223,887	$3,842,707

Accrued depreciation of $22,286,258 as of December 31, 1914, is $3,843,000 (or 17.244% based on 20% of Local and 15% of General Plant), which, divided by $1,701,816, equals 2.258% which is the depreciation annuity percentage required to build up a fund on a 4% sinking fund basis, equal to the estimated *accrued depreciation* of the property. The final column in this Table shows the correctness of this calculation.

Table V shows that maintenance, repairs and renewals have averaged 2.307%, which added to 2.258% (above deduced) is 4.565% (by sinking fund formula) for maintenance, repairs, renewals and accrued depreciation.

112 for maintenance and repairs, $280,152 for renewals and $373,-848 for accrued depreciation, we have a total of $933,112 as the amount that the Company actually spent and set aside for the year 1914.

We have already shown that, based on its history of 19 years, it would have been justified in spending and setting aside $971,072, or about $38,000 more than it did spend and set aside for up-keep and accrued depreciation in 1914.

The European war, which began the first of August, 1914, caused a falling off in growth of net income and it caused the Company to curtail its maintenance expenses somewhat below the normal.

A glance at the third column in Table V will indicate this fact. It follows, therefore, that the Company's practice as to expenditures for repairs and amounts set aside for depreciation reserve is substantially justified by its experience during its entire life of 19 years.

Let us now consider the Local and General property separately, for we have thus far considered them as combined. Table VI shows that the average percentage of expenditures for repairs and renewals has been 3.087% for the Local Property, and calculation shows that a depreciation annuity of 2.581% would have provided for the accrued depreciation upon a sinking fund basis, the sum of the two percentages being 5.668%. Table VI, column C, shows that, as charged on the Company's books, $1,150,979 has been spent during the 19 years for what has been termed maintenance and repairs. This is almost exactly 1.8% of the total in Column B, or in other words, the so-called "maintenance and repairs" has averaged 1.8% throughout this period. If we deduct this from the 5.668% we have 3.868% as the proper amount for annual depreciation charge of the Local property. As a matter of fact, the Company has been setting aside 3.36% for this item, from which it would appear that they have not been setting aside quite enough. However, as stated in the earlier part of this report, the only correct way to look upon the problem before us is to combine all charges for maintenance, repairs, renewals, and depreciation fund, since distinctions between maintenance, repairs, etc., have not been very carefully drawn in the past.

Table VII shows that for the General Property the total up-keep and depreciation has averaged 3.746% per annum. Table VII, third column, shows that the maintenance and repairs expenditures, as charged on the books of the Company, have totaled $748,573 in the 19 years. This is almost exactly 0.95% of the total depreciable property given in the second column. Hence, if we deduct this 0.95% from the total of 3.746% we have left 2.796% as the proper amount for depreciation reserve charge. As a matter of fact the Company has been setting aside in its depreciation reserve for General Property 2.42% from which it appears that it has not been setting aside quite enough, if we assume that its charges to maintenance and repairs have been precisely in accordance with modern definitions of these expenditures. But, as previously stated, the proper way is to look at the grand total up-keep and depreciation charges, and, as has been shown in the earlier part of this report, this grand total has been almost precisely in accordance with actual experience of the Company during the past 19 years. From this it may be inferred that the Company may have legitimately charged under maintenance and repairs slightly more than has appeared there in the past, but this would result in decreasing correspondingly the charges to renewals.

It cannot be too often repeated, perhaps, that the *sum total* of all up-keep charges, maintenance, repairs, renewals and depreciation constitutes the only reliable criterion by which to judge the equitableness of any up-keep charges made by a company of this

character. I think that the foregoing study establishes beyond doubt that the Company's allowances for depreciation reserve have been below rather than above what it might reasonably claim as sufficient.

Repair and Depreciation Costs of Electric Company. In another of our appraisals of an electric lighting property in a city of some 22,000 population we found by the foregoing method that, for a period of 24 years, the average cost of repairs and renewals was 5.03% of the average plant value and that, including depreciation, (on the straight line basis) the total for repairs, renewals and depreciation was 8.6% of the average plant value.

Repair and Depreciation Costs of Telephone Company. Using a method similar to the foregoing, in the Hearing of the Bell Telephone Company of Pennsylvania, Gillette showed that the average current maintenance and depreciation was 9.46% of the average book valuation of the physical property for a period of 29 years.

Cost of Repairs and Life of U. S. River Improvement Plant. C. W. Durham (Engineering and Contracting, Jan. 24, 1912) states that one of the tow boats used by the U. S. Engineer Corps on river improvement work on the Mississippi is 148 ft. long over all and 129 ft. on deck; width of hull 25 ft. 4 ins.; over guards 28 ft. 2 ins.; 5 ft. deep in the dead flat, and draws light 2 ft. 6 ins. Her wheel is 14 ft. wide, 18 ft. 3 ins. in diameter, and has 24-in. buckets. She has two propelling engines, 15.5 ins. diameter by 5 ft. stroke, and 3 boilers, 24 ft. long by 36 ins. diameter, with six 13-in. return flues in each.

Complete detailed costs of keeping wooden hull towboats in repair, for 3 boats of nearly the same size and power, built or purchased in 1881 show that while the repairs in 30 years amount to about three times the original cost of each boat, yet the cost per annum for a serviceable towboat is only about $1,400, and the salvage on each today would be about $5,000. These boats have all had new boilers and have been practically rebuilt as to their hulls two or three times. Repairs to cabins and machinery have been nominal.

TABLE IX. COST AND REPAIRS OF SMALL TOWBOATS

	"Lucia," built 1885. Oak hull	"Louise," built 1884. Oak hull	"Elsie," built 1889. Steel hull	"Emily," built 1889. Oak hull	"Ada," built 1889. Oak hull
Original cost...	$ 4,000	$3,538	$5,110	$4,034	$4,000
Repairs to Dec. 31, 1910......	12,575	11,495	7,450	10,442	8,251
Total	$16,575	$15,033	$12,560	$14,476	$12,251

The "Lucia" had new hulls in 1895 and 1910.
The "Louise" had new hulls in 1894 and 1905, the latter steel.
The "Elsie" has required no additional hull.
The "Emily" had new hulls in 1902 and 1910.
The "Ada" had a new hull in 1904.

A sample of the small auxiliary towboats attached to the U. S. plants is the "Grace," which is 92 ft. 6 ins. long over all and 78 ft. on deck; width of hull 17 ft. and depth 3 ft. 11 ins. She has a

wheel 10 ft. long and 12 ft. in diameter with 18-in. buckets; 2 cylinders 7.5 x 49 ins., and 2 boilers 10 ft. long and 30 ins. in diameter with 44 3-in. flues. The cost of this boat, which was built by the United States in 1894, at Keokuk, was $8,616.

The costs of other small auxiliary towboats are shown in Table IX.

These boats have cost the government about $500 a year each, and the salvage on each would be about $3,000.

A typical office-boat and quarter-boat used with the government plants is 50 ft. by 18 ft. in hull dimensions, and has a single-story cabin, nicely fitted with staterooms, bunks and office furniture. It was built in 1893, at a cost of about $1,800, including outfit. The repairs to 1907, during which year the hull was rebuilt, were small. Repairs to Dec. 31, 1910, were about $2,500, including maintenance of outfit. On Dec. 31, 1911, this boat was in fine condition.

Life of Scow Barges. Table X gives the life of scow barges on Mississippi River improvement work.

Life of Vessels on the Great Lakes and Tidewater. W. J. Wilgus in an appraisal of the Lehigh Valley railroad published in part

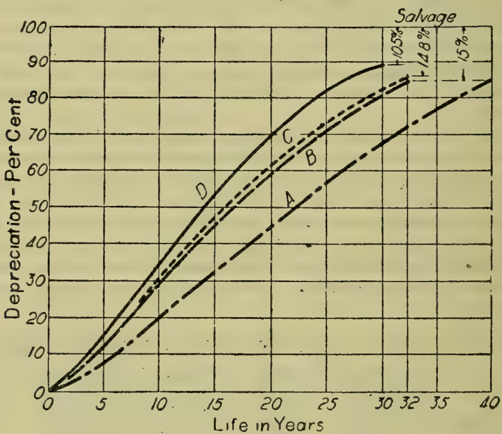


Fig. 1. Depreciation of marine equipment.
A — Steel steam vessels on Great Lakes.
B — Steel steam vessels on tidewater.
C — Steel barges, floats, etc., on tidewater.
D — Wood tugs, barges, etc., on tidewater.

in Engineering Record, May 30, 1914, states that floating equipment of roads connecting the Great Lakes and tidewater may be divided into the following types: (a) Steel steam vessels on the Great Lakes, (b) steel steam vessels for tidewater service, (c) steel barges, car floats, etc., for tidewater service and (d) wood tugs, barges and miscellaneous, for tidewater service.

TABLE X. LONGEVITY OF SCOW BARGES

Dimensions, feet.	Material.	Cost, each	Years in service.			Repairs		
			Max.	Min.	Av.	Max.	Min.	Av.
100 x 20 x 4	White pine.	$1,600	15	14	15	$1,454	$1,086	$1,283
100 x 20 x 4	White pine.	768	15	9	12½	1,783	349	1 067
100 x 20 x 4	Fir.	1,300	22	15	21	2.871	447	2 066
100 x 20 x 4	Fir.	770	8	6	7¼	681	91	367
100 x 20 x 4	Fir.	770	8	6	7½	561	134	264
100 x 20 x 4	Fir and pine.	806	16	13	14¼	1,323	628	1,052
100 x 20 x 4¼	Fir.	800	17	15	16⅔	881	564	716
110 x 24 x 4½	Fir.	806	14	12	13	958	661	822
110 x 24 x 4½	Fir.	790	15	11	14	1,780	517	1,314
120 x 20 x 5	Pine with oak bottom.	1,400	14	13	13⅓	1,097	802	911

Progressive percentages of depreciation are proper, as shown in Fig. 1, all on the basis of regular annual expenditures for proper upkeep, but not embracing extraordinary expenditures for new boilers, new houses or new equipment like electric-light plants or steam steering gear.

Methods of Handling Battery Maintenance Charges for a Large System. We have abstracted the following from Electrical World, Dec. 16, 1916. In outlining the handling of storage-battery maintenance funds on the Boston Edison Company's system at a recent hearing before the Massachusetts Gas and Electric Light Commission, L. L. Elden stated that the company operates about fifteen storage batteries representing an investment in the vicinity of $800,000, and that during the last year maintenance requirements amounted to about $30,000. In the purchase of a battery it is customary for the manufacturer to give the company a seven-year guarantee, during which the manufacturer keeps the battery in proper physical condition and maintains its stated capacity. During the guarantee period the manufacturer replaces any defective plates or boxes that are clearly due to manufacturing defects. If the company damages a cell in handling, the expense of repairs is assumed by it. At the end of the guarantee period an amount of money is set aside for each battery, depending upon its age and upon what has already been expended upon it.

The Edison company estimates what the probable life of the battery plate is expected to be, with the cost of renewing the plates, and according to such figures a sum of money representing the estimated future repair charge is pro-rated into a monthly charge credited to the use of the battery. Unlike many other pieces of apparatus, a battery may in some unusual occurrence go to pieces in a day, and the amount of depreciation or wear and tear upon the plates is not readily ascertainable at any particular period; hence it is deemed best by the company to pro-rate the renewal charge on these plates over a fixed period rather than to have an abnormal and unequal distribution of expenses due to the company's having to spend say $2,500 on one battery in one month for a complete renewal. The batteries are of various ages and the prospective repair account cannot be taken care of at any one time until the condition of a battery permits it. Mr. Elden said that the number of kilowatt-hours delivered by a battery in a year affords no criterion of the severity of use made of it, since excessive discharges due to accidents, short-circuits or operating conditions may depreciate the plates far more than liberal use within the proper range of discharge. In a single year there may be twenty occasions when battery discharges will be utilized temporarily to overcome adverse operating conditions and maintain the normal standard of service.

Cost of Repairs of Buildings. Data, April, 1912, has the following cost of labor and material for estimating repairs to buildings, from the Chicago Building and Construction Co.

Carpentry:

Carpenter labor costs 60 cts. per hour, plus contractor's profit. Eight hours constitute one day.

13/16 by 5¼-in. Common Yellow Pine flooring costs $25.00 per M. 13/16 by 3¼ — $23.00 per M.

1 by 4 or 1 by 6-in. White Norway C. Pine flooring costs $40.00 per M.

Labor for laying 5¼-in. Pine flooring $2.00 per square; 3¼-in. $2.50 per square.

13/16 by 2¼-in. face clear Maple flooring costs $42.00 per M.

Labor for laying 2¼-in. face Maple flooring, smooth for oil finish, $3.50 to $4.50 per square.

13/16 by 2¼-in. faced plain White Oak flooring costs $56.00 per M.

13/16 by 2¼-in. faced quarter sawed White Oak flooring costs $88.00 per M.

Labor for laying and scraping oak floor 2¼-in. face, for wax or varnish, $5.00 to $6.00 per square.

Smoothing and scraping oak floors alone costs $2.50 to $3.50 per square.

Base, Pine, 2 member moulded, put down, 8 cts. per running foot.

4 and 6-in. clear Northern Pine beveled siding costs $32.00 per M.

4 and 6-in. clear Washington Red Wood bevel siding costs $33.00 per M.

4 and 6-in. clear Washington Spruce bevel siding costs $26.00 per M.

Labor for putting on siding $2.75 per square, for 4 to 6-in. siding; for narrow mitered siding $3.75 per square.

Labor for putting on shingles, $2.50 to $3.00 per thousand shingles.

Best grade of clear Red Cedar shingles cost $4.50 per thousand.

Common No. 2 Pine doors, complete with frames, placed in position, with hardware, not painted, cost $8.00 to $12.00 each.

Fancy Oak front doors, complete, placed in position, with hardware, cost $15.00 to $25.00 each, according to style.

Oak veneered doors, 1¾-in. Pine core, complete with frame, placed in position, with hardware, $12.00 to $15.00 each.

Mantels — Hardwood, artistic design, complete with mirror and grate, set $45.00 to $65.00 each.

Grilles. Fancy Oak, $1.25 to $1.75 per lineal foot set.

Windows, with sash, frame, casing, cords, weights complete, put in, $9.00 to $12.00 each. If hardwood frame and trim, with sash, $12.00 to $14.00.

Stairs. Common Oak, without rail, $2.50 per riser, labor included.

Stair rail. Oak, moulded design, 30 cts. to 35 cts. per running foot, labor included.

Stair rail. Pine, moulded design, 15 cts. to 25 cts. per running foot, labor included.

Balusters. Pine, fancy turned, 12 cts. to 15 cts. each; Oak 15 cts. to 30 cts. each, labor included

Newels. I-in. quarter sawed Oak, moulded cap, $6.00 to $9.00; Plain Oak, $5.00 to $7.00; Pine, $4.00 to $6.00 each, labor included.

Porches. Front, frame, ordinary construction, 6 to 7 feet wide, shingle roof, ceiled, square or turned columns, frieze and cornice, balusters at floor, complete, $8.00 to $10.00 per front foot measure; 12 by 12-in. stone pillars under porches, $1.00 per lineal foot.

Painting and Glazing:

Painting, two-coat work, costs 20 cts. per square yard.

Painting, three-coat work, costs 25 cts. per square yard.

Painters' labor costs 55 cts. per hour, plus contractor's profit.

Calcimining costs $3.00 to $5.00 per room for small rooms, and 60 cts. per square for large rooms.

Note.— To ascertain the number of square yards of painted surface, multiply the length by the width, in feet, and divided by 9, and the result will be the number of yards.

Lattice work and stair balusters are counted double.

For reglazing old work, add 20 to 50% to cost of glass, according to quantity set.

Wall Paper:

Cost of hanging, 15 cts. to 30 cts. per single roll for ordinary work, according to quality of paper.

Three and one-half rolls will cover one square.

Plastering:

Two coats of plastering repair work cost 40 cts. per sq. yd.
Three-coat work costs 50 cts. per sq. yd.
For cement plaster add 10 cts. per sq. yd. extra.
Plaster labor costs 68¼ cts. per hour, plus contractor's profit.
Plasters' helper costs 40 cts. per hour.
Lathers' labor, $5.00 per day of eight hours.

Note.—To ascertain the number of yards of plaster, multiply the length of the ceiling by the width. Do the same with each side wall and add all together, divide by 9 and the result will be the number of yards. Make no deductions for openings unless very large.

Plumbing:

30 gal. iron boiler, connected	$15.00 each
Enameled sinks, 18 by 24 ins., connected	10.00 each
5-foot enameled bath tub, connected	35.00 each
Porcelain washout-closet with tank, connected	25.00 each
Hopper closet, connected	20.00 each
Laundry tubs, 2 divisions, cement, connected	20.00 each
Wash bowls, plain marble slabs, connected	25.00 each
Brass faucets, put on	2.00 each
Plated faucets, put on	2.25 each

6-inch iron soil pipe, put in, $1.00 per running foot.
4-inch iron soil pipe, put in, 60 cts. per running foot.
Plumbing labor costs $5.50 per day of eight hours, plus contractor's profit.

Sewers:

6-in. sewer, ordinary digging, laid with proper drain, well cemented, 50 cts. per lineal foot.
Traps, $1.50 each.
Elbows, $1.25 each.
Catch basins, 5 by 6, stone cover, $15.00.

Electric Wiring:

To estimate the cost of electric wiring in ordinary buildings, ascertain the number of lights and multiply same by $3.00.

Gas Piping:

To estimate cost of gas piping in ordinary buildings, ascertain the number of lights and multiply by $2.50.
Gas Pipe put in, connected, 20 cts. per running foot.
Gas Fitters' labor costs $5.50 per day of eight hours.

Roofing:

Gravel Roof, 3-ply, $3.50 per square.
Gravel Roof, 4-ply, $4.00 per square.
Gravel Roof, 5-ply, $4.25 per square.
Slate roof, ordinary black slate, $10 to $12 per square.
Slate roof, fancy green and red, $15 to $30 per square.
Best galvanized iron roofing, standing seams, $9.00 to $12.00 per square, painted.
Best tin roofing, standing seams, $8.00 to $11.00 per square, painted.
Tile roofing, $12.00 to $15.00 per square, according to design.

Metal Ceilings:

Fancy metal ceilings with cornice cost $8.00 to $12.00 per square.
Corrugated Iron Ceiling, $6.00 to $7.00 per square.

Stone Work:

Common rubble stone, 100 cu. ft. to the cord, costs, laid in wall, $20 to $25 per cord, according to location and necessary hauling.

Rock face, 4-in. Bedford stone for facing, furnished and set in wall, costs $1.75 to $2.25 per square foot face measurement.

Mason labor costs 67½ cts. per hour, plus contractor's profit.

Mason helper costs 37½ cts. per hour, plus contractor's profit.

Brick Work:

Common brick, furnished and laid in 12-in. wall, costs $15.00 per M, wall count.

Pressed brick, for facing, laid in wall, colored mortar, rodded joints, add to cost or brick $10.00 to $20.00 per thousand for laying, according to character and design of front.

Cement Work:

12-in. block walls cost about the same as 12-in. common brick wall, laid, less 25% of the cost of brick for a similar wall.

Concrete basement walls cost 28 cts. per cubic foot, wall measurement.

Cement sidewalk costs 12 cts. to 15 cts. per square foot.

Cement basement floors cost 10 cts. per square foot.

Chimneys:

Ordinary single flue chimneys cost $1.00 per lineal foot. For double flue $1.75 per lineal foot.

Interior Marble Work:

(For Wainscoting and Floors in Apartment houses and Office Buildings.)

Wainscoting, Italian, White, $1.00 per sq. ft. set.

Wainscoting, English Vein Italian, White, $1.05 per sq. foot, set.

Wainscoting, Tennessee Marble, 80 cts. per sq. ft., set.

Wainscoting, Vermont White Marble, 95 cts. per sq. ft., set.

Wainscoting, Vermont Green Marble, $1.60 per sq. ft., set.

Floors. Marble and Mosaic. Marble Tile, 80 cts. per sq. foot, laid; Mosaic, 75 cts. per square foot, laid.

To Estimate Cost of Radiation per Cubic Foot:

(Direct Radiation.)

Steam Heat — Allow 1 foot radiation for each 50 cu. ft. of space. Figure radiation at 72 cts. per radiation foot.

Hot Water Heat — Allow 1 foot radiation for each 30 cu. ft. of space.

Figure radiation at 75 cts. per radiation foot.

The above is for average rooms. If rooms have extraordinarily large window exposure, increase radiation. If smaller window space than average, decrease radiation.

Be careful in the distribution of radiation, as the success of a heating plant depends largely upon arrangement and location of radiators.

The Cost of Freight Car Repairs. The following is taken from the Railway Age Gazette, June 14, 1907: One Western Road has compiled figures for the fiscal year 1906 which distribute the repairs to freight cars somewhat roughly under a few heads as follows:

Items	Material %	Labor %	Total %
Wheels and axles	15.0	1.6	16.6
Remainder of trucks	9.2	3.3	12.5
Draft gear	12.2	7.2	19.4
Sills and under-framing	6.1	3.4	9.5
Super-structure	15.9	9.8	25.7
	8.1	2.5	10.6

Items	Material %	Labor %	Total %
Doors, side and end	1.6	1.0	2.6
Doors, grained	0.6	0.6	1.2
Roof	1.2	0.7	1.9
Total	69.9%	30.1%	100.00%

The average number of times each car was repaired was 5.5.

Comparative Costs of Repairing Steel and Wooden Cars on a Harriman Line. The following is from the Railway Age Gazette, June 14, 1907: A record of comparative costs of repairs to steel and wooden cars on the Harriman line to February, 1907, was given through the courtesy of Mr. Kruttschnitt, and represents a period of 2.5 yrs. A statement gives the average number of cars of each plant for the period, total cost of repairs for same, and the average cost per car per month.

Kind of car	Average number of cars	Total cost of repairs	Average cost of repairs per car per month
Steel cars, ballast	460	$71,291.81	$5.17
Box	2,304	108,323.29	1.57
Coal	1,594	165,959.57	3.47
Dump	300	39,322.92	4.37
Flat	2,289	72,024.30	1.05
Furniture	297	32,198.04	3.61
Gondola or ore	1,419	134,019.10	3.16
Oil	871	261,613.43	10.01
Stock	1,693	55,908.34	1.10
Total	11,227	$940,660.90	$2.79
Wooden cars, ballast	457	$65,560.89	$4.78
Box	6,247	735,405.53	3.92
Coal	127	14,329.81	3.76
Flat	514	15,699.75	1.02
Furniture	278	61,999.51	7.44
Oil	247	96,910.90	13.05
Stock	2,700	291,940.19	3.61
Total	10,568	$1,281,846.58	$4.04

The unusually high cost of repairs to the oil cars was due to the fact that these cars were new equipment, upon which it was deemed advisable to make a number of alterations which were charged in the repairs accounts. Current repairs on these cars are not expected to average any higher than on other equipment.

The gradual increase in the figures for average cost of repairs per car per month in comparison with the past year's record is to be noted. The average cost of repairs per car per month for the steel cars has increased from $2.42 to $2.79, and for the wooden cars, from $3.74 to $4.04, the percentages being respectively 15 and 8%.

Life and Maintenance of All-Steel Cars. The following article by M. K. Barnum, Supt. of Motive Power, B. & O. R. R., is from the Railway Age Gazette, March 3, 1916: When the first steel cars were built, the advocates of this form of construction claimed that these cars would be practically indestructible, and their life so

much greater than that of wooden cars that it was very difficult to estimate it. A few years later, when steel cars came into general use on the larger railroads, the estimates of their life were placed at from 25 to 35 years, and in calculating the rate of depreciation, many roads adopted three per cent. per year, whereas for wooden cars, it had for a long time been calculated at six per cent. It is now nearly 30 years since the first steel cars were built, and there has been a considerable difference in their durability. This has been found to vary according to the manner in which they have been maintained, the part of the country in which they have been mostly used, and somewhat with the character of the lading. However, on the whole, the life of steel freight cars is found to be much less than that originally expected.

So far as the writer has been able to learn, the oldest steel freight car now in service belongs to the Bessemer & Lake Erie. It was built in 1896, twenty years ago. The frame of this car was made of structural steel shapes, and it weighed nearly 42,000 lbs., about 4,000 or 5,000 lbs. more than many cars of the same capacity which were built later. A photograph taken in 1915, shows that the design of this car compares very favorably with the latest methods of construction, and also indicates that it has been very well maintained. The record of repairs shows that it has been kept well painted, this being the usual practice of the Bessemer & Lake Erie. Some of the doors and hoppers required new sheets after about nine years and at 14 or 15 years of age the floor sheets required extensive renewals and the side sheets and stakes had some repairs. At 18 yars it received a new floor, two new corner side sheets, eight new hopper sheets and other repairs, and its appearance indicates that it may be good for at least 10 years more.

This car is apparently an exceptional case, for we find many thousands of steel gondola and hopper cars only *14 and 16 years* old which have the sheets and underframes so weakened by corrosion and service that they do not justify the application of new material for general repairs, and many of these cars are now being destroyed on account of the bodies having reached their limit of life. This is about one-half the life which was originally expected from steel cars, and it is disappointing. It naturally follows that those roads which have calculated the depreciation of steel freight cars at three per cent., and now find many of them worn out at the age of 14 to 16 years, must charge quite a large amount to operating expenses when they have to be scrapped. If we assume the average life of a steel gondola car which cost $1,000, as 16 years, and the scrap value of the car to be $200, five per cent. per year would be about the proper rate to be used in figuring depreciation.

Life of Wooden Coal Cars. The records of a number of roads owning large numbers of wooden coal cars show that their life has varied between 16 and 20 years, and the average life has been about 17 years. This class of equipment has usually been condemned and dismantled on account of the underframes and draft attachments becoming worn out and too weak for the heavy modern

trains of coal cars. But for this reason, the life of these cars undoubtedly would have been about 20 years, which is the average life of a box car. However, in comparing the life of wooden coal cars with that of steel, we should bear in mind the fact that most of the wooden cars are of 20 and 30 tons' capacity and few, if any, are over 40 tons, whereas few steel coal cars have been built of less than 40 tons' capacity and the majority of them carry 50 tons, while some are now being built to carry 75 and 90 tons.

Life of Iron and Steel Bridges. The writer has obtained the views of a number of bridge engineers and engineers of maintenance of way, and most of them say that the life of iron and steel bridges varies indefinitely, so far as actual durability is concerned, provided they are kept well painted, as they usually are, and the ordinary repairs are maintained. In some cases iron bridges 30 and 40 years old have been perfectly good so far as deterioration is concerned and have only been removed on account of the locomotives and cars becoming too heavy for their construction. Bridges which are exposed to salt air and water corrode rapidly and their life is comparatively short, and salt water drippings from refrigerator cars used for shipping fresh meat tend to corrode the girders quite rapidly where the amount of this class of business is large. In comparing the life of iron and steel bridges with that of steel freight cars, we find the principal differences to be that the bridges are kept well painted and their life is not shortened as much by corrosion as is that of freight cars which are not kept painted on the inside. Many cars are not kept painted on the outside, and they are subject to more severe and frequent shocks in service.

Life of Locomotive Tenders. The locomotive tender more closely approaches the steel coal car in the service to which it is subjected and will afford a fairer comparison on this account. Locomotive tenders are usually kept well painted on the outside, and whenever the locomotive receives general repairs, ordinarily once in about two years, it is thoroughly cleaned and painted outside, and often a coat of paint is applied to the coal space and to the top and bottom sheets. Many locomotives, thirty or more years old, still have the original tender in fairly good condition. On some of these the inside sheets have been renewed, but in many the original outside sheets are still in a fair state of preservation.

Principal Causes of Short Life of Steel Cars. There are many causes which tend to shorten the life of steel cars and the most active of these is corrosion. New steel cars are painted inside and out, but very few, if any, railroads attempt to keep the inside painted after the cars have gone into service, as it is thought that the effect of loading and unloading coal, ore, etc., is to wear the point off so quickly that it would not last long enough to pay for the cost of the application. Therefore, the corrosion of the inside of such cars generally starts within a few months after they go into service. The paint on the outside varies in durability according to quality, the number of coats applied, and the manner of application, but it is nothing unusual to see cars only two or three years old the sides of which have begun to rust quite badly and

cars only five years old with but little paint left on them. It is pretty certain that if these cars had been repainted when two or three years old, before the rust had become so general, the corrosion on the outside would have been stopped and the life of the side sheets prolonged.

Some of the earlier steel cars were built so light, that they have become weakened by corrosion sooner than those of heavier construction, and such cars occasionally buckle up in trains. In designing steel cars, it has been a nice problem to determine just how far to go in putting in metal to increase the strength, and at the same time to cut out metal where it is not essential so as to keep the dead weight down to a minimum consistent with good service. In this respect, the practice of different roads varies so that we still see steel gondola cars of 100,000 lbs. capacity weighing only about 38,000 lbs., while others of the same capacity weigh 7,000 or 8,000 lbs. more. This matter of keeping down the dead weight has always been a hobby of such prominent railroad builders as E. H. Harriman and J. J. Hill, and little argument is needed to prove the desirability of keeping the dead weight as low as may be consistent with satisfactory service. The tendency during the past four or five years has been to increase, somewhat, the weight of cars, but this has generally been done, not by using thicker sheets for the sides and bottoms, but by strengthening the sills and reinforcing the top edges of the sides and ends, and also by adding more substantial draft gear. These improvements should increase somewhat the life of these cars over those of earlier design, but in view of the heavier trains in which they are used it remains to be seen how far this will prove true. These problems of keeping down the dead weight of cars and eliminating those of weak design are not new, for in the proceedings of one of the earliest meetings of the Master Car Builders' Association, held nearly 40 years ago, we find a lengthy discussion about these same questions and at that time it was the consensus of opinion that in the 15-ton car the maximum capacity had finally been reached.

Other causes of the short life of steel cars are the strains to which they are subjected in unloading machines and also the use of sledges and bars in pounding the sides and hoppers when the coal freezes or clogs and requires loosening. Some of the later designs of cars are provided with holes framed into the sides and hoppers, through which bars can be introduced to loosen the coal when it lodges. Another cause of shortening their life is the heavier trains in which they are used, resulting in greater shocks than those for which they were originally designed. The effect of climate has quite an important bearing on the life of steel cars as there is a noticeable difference in the rapidity of corrosion of cars used mostly in proximity to salt water and to rivers where fogs are prevalent, and those which are kept principally in service in the dry climate west of the Missouri river. The writer's observations lead him to believe that corrosion is probably 25 per cent. more rapid in the vicinity of the salt water than in the drier climate of the interior. The nature of the loading also affects the deterioration. One road

which uses steel hopper cars almost entirely in iron ore service reports that, "as yet none of them show any effects of deterioration due to rust," although they are about 16 years old. Coal having much sulphur and other impurities is more injurious to steel sheets than the better grades of coal, and wet ashes from cinder pits are especially active in hastening corrosion.

Difficult Problems. For the first five or six years of the life of a steel car the repairs are light and it is easy to decide just what work should be done, but after eight or ten years the floor and hopper sheets of many cars have become so corroded that they must be renewed, and in some cases the sides also rust through at the ends and bottom while the rest of the sheets are worth preserving. After a few years more many cars become so generally corroded that it is doubtful whether the side sheets are strong enough to make it advisable to rivet new bottom and hoppers to them. Then the problem is whether to apply new side sheets, if the car has already had a new bottom and hoppers; or, in cases where these have again become weakened, to give the car general repairs using such of the original parts as may yet be serviceable; or to build an entire new body using the same trucks; or to dismantle the car entirely and eliminate it from the equipment list. Under these conditions the program will be more or less affected by the capacity of the car and the desirability of improvements in the design and the operating mechanism.

When steel cars become damaged in wrecks, the question of repairs is quite a different one from that of repairing wooden cars, as in the latter case the damaged parts are removed and replaced with new sills, siding, flooring, etc., at a considerable expense for material. On the other hand, unless a steel car is damaged almost beyond recognition, the various parts can generally be straightened out and replaced on the car, if they were previously in good condition. One road, owning over 100,000 steel coal cars, has lost only about 20 of them on account of being damaged beyond repair, but if these had been wooden cars, probably many hundreds of them would have been destroyed within the same period.

On another road which has over 50,000 hopper and gondola cars, only about two per cent. of the all-steel cars were damaged beyond repair during the first 12 or 13 years of their life, but of the composite cars having steel frames and wood sides and bottoms, about 11 per cent. were destroyed. This large difference was probably affected to some extent by the fact that the composite cars were not originally as well designed as the steel cars, but after making due allowance for this, the all-steel cars seem to have the advantage over the composite cars in the matter of durability.

Rebuilding Steel Cars. On a road which owns a large number of steel gondola and hopper cars, the latter have been found to reach the limit of the profitable life of the body in about 13 or 14 years. When the cars were from eight to ten years old, it became necessary to renew the floor and hoppers, and in about four or five years more, the sides and other parts had become practically worn out, so that it was very doubtful whether the bodies were

worth the application of more new material for repairs. A study of the subject indicated that an entire new body would cost only about $25 more than general repairs to the old body, retaining such parts as might be fit for further service. The trucks were in good general condition so that with the renewal of some worn parts, they could be made practically equal to new. The body after receiving general repairs was estimated as worth only about 65 per cent. of the value, new, of a gondola and 75 per cent. of a new hopper car, whereas the general repairs would probably not extend the life of the car more than six or eight years. The repaired car, if destroyed on a foreign line, would have its depreciation calculated from the date of its original construction, whereas the new body would have its depreciation calculated from the time when the body was built, which made a good argument in favor of a new body.

Other points in favor of the new body were that with the experience obtained from the maintenance of the old bodies, some improvements in the design were possible which would make the new body more satisfactory in service and better able to withstand the effects of heavy trains, dumping machines, etc. It would also have the further advantage of not being on the repair tracks as often as the repaired car. It was, therefore, decided to buy new bodies to replace the old hopper bodies of 100,000 lbs. capacity and use the air brakes, couplers, draft gear and trucks of the old cars under the new bodies. In the case of the 80,000 lb. gondolas it was not thought profitable to perpetuate a steel car of this capacity, and therefore it was decided to use the trucks and other serviceable parts under new box and stock car bodies of 80,000 lbs. capacity. In cars which had reached the limit of their life on account of the sheets being so generally weakened by corrosion there was not enough good material left in the bodies to justify general repairs. The bodies of these old steel cars were cut down by using a heavy broad-axe to cut the thinner sheets. The oxy-acetylene blow-pipe process is used to cut the angles, sills and heavier sheets. By these methods, the total cost of cutting down a condemned steel hopper car body to sizes suitable for sale, was less than $6, including both labor and oxy-acetylene gas. Some of the end sills, gussets, side stakes and other parts of the condemned cars were considered worth saving for repairs to other cars which are to be maintained for a time.

Painting Steel Freight Cars. There has been a good deal of discussion as to whether or not it pays to keep steel coal and ore cars well painted and the majority of superintendents of motive power believe that it would pay to do so, but many of the higher officers who are responsible for the entire cost of operation seem to have concluded that it does not pay to paint them except when they receive new sheets or the letters and numbers need to be brightened up so that their ownership and identity can be distinguished. A committee of the Master Car Builders' Association investigated this subject several years ago and their conclusions as presented at the 1908 convention were as follows:

"We cannot be too emphatic as to the necessity of taking the proper care of the exterior, and regret that we are not able to give the interior the same care.

"The painting of the inside of steel cars has been thought by some to be beneficial, but your committee can see no lasting results in this, and do not recommend it, but is of the opinion that coating the interior of the cars about once every six months with black oil would act as a preservative."

During the following year a number of cars were painted with different mixtures for test purposes and special attention was given to painting the insides of the cars. At the 1909 convention the committee reported upon the painting of the inside of cars as follows:

"One car bearing mixture No. 4 was examined after being in service 4 months and 17 days and shows the inside well preserved, but considerable of the paint gone from the bottom, yet there seemed to be retardation of the rusting and no accumulation of scale. This mixture shows better results than mixtures Nos. 1, 2, and 3." (Mixture No. 4 consisted of 30 lbs. of tar, 40 lbs. of aniline oil and 170 lbs. of corn oil.)

However, the committee's conclusions were, "It will be a very hard matter to find a preservative that will take care of the interior. The best preservative is to keep the cars in active service. Some steel cars that have been in active service for 10 years have the plates in excellent condition and from appearances, they are good for 10 years more. It is a pretty well known fact that where cars stand idle for a couple of months, the deterioration of plates on the inside is equal to two or three years' service."

Similar opinions were expressed by several of the members of the Association who took part in the discussion. So far as the exterior of the car was concerned, practically all those discussing the report gave it as their opinion that they should be kept well painted. Nevertheless, this practice has not been generally followed.

As to the frequency with which steel cars should be painted, there is quite a difference in opinion. Some roads paint them once in every three years, others once in four or five years and others only when they receive new sheets in the course of repairs. Estimates of the cost of painting also vary widely, and as might be expected, those roads which paint their cars most infrequently are the ones on which the cost of painting is high, varying from $5 to $10 for each painting, while those roads which keep their cars well painted report the cost as varying from $6 to $1 for each painting. There would naturally be a considerable variation in the cost per painting according to the kind of material, the class of labor used and the condition of the car when painted, but a comparison of the figures indicates that it cost but little more during the life of the car to keep it well painted than it does to paint it only when the car becomes badly corroded and requires more thorough treatment.

The difference in the average age and condition of such cars as have been kept well painted and those which have not been so

well maintained, makes it seem fair to conclude that thorough painting will probably prolong the life of steel freight cars between 25 and 50 per cent. Assuming that the average life of a car is 16 years, and that the cost per painting would be $5, it seems very probable that an expenditure of $25 or $30 additional for painting would prolong its life one third, or about five years. This is a conservative estimate and it would certainly be a good investment when applied to cars costing $1,000 apiece. Some other arguments in favor of keeping steel cars well painted are, that it will help to prevent their becoming weakened by corrosion so that they are liable to buckle up in heavy trains, also that the appearance of cars will be much better and although this may have no commercial value, yet it tends to create a favorable impression about the owning road. The arguments which are often advanced against keeping steel coal and coke cars thoroughly painted, seem frequently to be applied to steel underframes and other parts of cars which do not come in contact with the lading, and these are often found to be so corroded that their life is much shortened.

Steel Passenger Cars. The estimated life of steel passenger cars has been placed by various authorities at from 30 to 50 years, but as none of them are yet half that age there are no data at hand on which to base any definite conclusions. The elements affecting the deterioration of steel passenger cars are different from those which apply to freight cars, but several years' experience with such cars shows conclusively that they must be kept well painted or they will deteriorate more rapidly than wooden cars. Cases have been noticed where the doors and window frames which were made of pressed steel shapes, have begun to rust badly within two or three years and for this reason the Pullman Company and some railroads have returned to the use of wooden window sash in their more recent equipment. Also some of the railroads that used metal doors on their first steel passenger train cars found so many objections to them that they have been discarded and wooden doors used in the later cars. The parts of steel passenger cars which start first to rust are the roofs and the moldings or joints between the sheets at the clerestories and eaves, and there can be no doubt about the importance of keeping these parts well painted.

Conclusions. 1. The average life of steel gondola and hopper cars will probably be about 16 years, judging by the records of those cars which have already reached their limit of life.

2. The depreciation of steel gondola and hopper cars should be calculated at about five per cent.

3. It will pay to keep steel cars well painted on account of preserving their strength and improving their appearance and extending their life.

Since the notes used for this article were made, there was presented at the December meeting of the Pittsburg Railway Club a paper on "The Life of a Steel Freight Car," by S. Lynn, master car builder of the Pittsburg & Lake Erie, and it is interesting to note that the points mentioned in his paper as well as those brought out in the discussion, agree in most of the essential facts with the

observations and conclusions contained in this article. Two statements made in the discussion are especially worth quoting, namely:

"If the steel car was given reasonable treatment and repairs made when needed, and repainted when the steel became exposed to the weather, the renewing of some of the parts would not become necessary for a longer period than is now the case."

"One of the most important things determining the life of a steel car is the question of maintenance. If you spend the right amount of money at the right time, you can get prolonged life and service."

Cost of Locomotive Repairs. Engineering and Contracting, Dec. 7, 1910, has the following: The costs of maintaining locomotives as submitted to the Interstate Commerce Commission for the fiscal year ending June 30, 1909, are interesting. In the following table of costs, Table XI, for which we are indebted to the American Engineer, the unit employed corresponds closely to the one recommended by the committee. This is the "work unit," which is equal to traction effort in pounds multiplied by locomotive miles and divided by 1,000,000, the latter figure being an arbitrary one used for reducing results to a convenient size for comparison. The wide variation in costs is due to differences in operating conditions — mainly, differences in grades and curvature — prevailing on the different roads. No division is made between running and shop repairs.

TABLE XI. COSTS OF MAINTAINING LOCOMOTIVES PER WORK UNIT

New England:	
New York, New Haven & Hartford	$3.30
Boston & Maine	2.75
Average	3.03
Eastern District:	
Pennsylvania R. R.	3.50
Pennsylvania Co.	2.80
New York Central	2.25
Baltimore & Ohio	2.35
Erie	4.80
Lake Shore & Michigan Southern	1.95
Philadelphia & Reading	3.65
Lehigh Valley	3.65
Delaware, Lackawanna & Western	2.45
Average	3.04
Central and Southern District:	
P., C., C. & St. L.	2.90
Southern Ry.	2.45
Louisville & Nashville	3.00
Illinois Central	3.80
Average	3.04
Middle Western District:	
Chicago, Burlington & Quincy	3.20
Chicago & Northwestern	2.70
Chicago, Rock Island & Pacific	3.30
Missouri Pacific	3.20
Union Pacific	3.70
St. Louis & San Francisco	3.70
Average	3.30

Southwestern District:	
Southern Pacific	4.35
Atchison, Topeka & Santa Fe	3.30
Average	3.83
Northwestern District:	
Northern Pacific	2.40
Chicago, Milwaukee & St. Paul	2.70
Great Northern	2.15
Canadian Pacific	3.90
Average	2.42

Cost of Repairs for Polyphase Motors. The following, Table XII, is part of a table, from the Journal of Electricity, May 1, 1917, showing the approximate cost of repairs for polyphase motors used originally in connection with an article which appeared in the January 1, 1916, issue of the Electrican Review and Western Electrician. This table has been revised to take into account the increased cost of the materials entering into such repairs and therefore bring the estimates more in line with the present cost of this work. The subject matter of the original article is given in the following paragraphs in a condensed and slightly changed form.

The table is suitable for 60-cycle two or three-phase squirrel-cage motors wound for any of the standard voltages from 110 to 550 inclusive.

For most of the sizes listed the costs were arrived at by taking the average cost of repairs for a given frame and then applying this cost to the various ratings built in that frame. This will be apparent by comparing the costs for the different ratings. Take for example, frame G. The cost of rewinding the stator is $34.75, This figure has been applied to the following ratings all of which are built in that frame: 1 horsepower, 900 revolutions per minute; 1.5 horsepower, 1200 revolutions per minute, and 3 horsepower, 1800 revolutions per minute. The frame sizes specified do not apply to any particular line of motors, but were arbitrarily chosen for the purpose of this article. However, the relative output of a given frame at the different speeds will be found to agree quite closely with several lines of induction motors on the market.

These estimates may also be used equally well for motors of other frequencies by taking the figures applying to a 60-cycle rating built in the same frame. This comparison can be easily made by referring to the manufacturer's rating and dimension sheets for that particular line of motors. The tables may be further applied to slip-ring or phase-wound motors, since the cost of rewinding the rotor of such a machine will not differ materially from the cost of rewinding its stator. On this basis the cost of completely rewinding a 10 horsepower, 1800 revolutions per minute slip-ring motor built in frame J will be $119, or $59.50 for the rotor or stator separately.

The estimates for rewinding the stator or resoldering the rotor do not include any preliminary work required to put the stator structure in fit condition to receive the new winding or work required on the rotor before the actual resoldering can be started. In other words, the figures cover only the actual rewinding or

TABLE XII. COST OF REPAIRS FOR 60-CYCLE POLYPHASE MOTORS

Horsepower	Synchronous speed in R.P.M.	Frame size	Stator winding	Resoldering rotor	Bearing linings per set of two	Painting	Recrating
.5	1200	C	26.25	2.50	1.35	1.00	1.00
.5	1800	A	24.25	2.25	1.35	1.00	1.00
.75	1200	E	28.00	3.00	1.85	1.00	1.00
.75	1800	B	24.25	2.25	1.35	1.00	1.00
1	900	G	34.75	4.00	3.10	1.50	1.50
1	1200	F	28.50	3.00	1.85	1.25	1.00
1	1800	C	26.25	2.50	1.35	1.00	1.00
1.5	1200	G	34.75	4.00	3.10	1.50	1.50
1.5	1800	E	28.00	3.00	1.85	1.00	1.00
2	1200	G	34.75	4.00	3.10	1.50	1.50
2	1800	F	28.50	3.00	1.85	1.25	1.00
3	900	I	53.50	6.50	5.25	1.50	1.50
3	1200	H	48.50	4.75	3.55	1.50	1.50
3	1800	G	34.75	4.00	3.10	1.50	1.50
5	900	K	73.75	8.75	8.05	1.75	2.00
5	1200	I	53.50	6.50	5.25	1.50	1.50
5	1800	H	48.50	4.75	3.55	1.50	1.50
7.5	900	L	70.75	12.00	7.85	2.00	2.50
7.5	1200	J	59.50	7.00	6.60	1.75	2.00
7.5	1800	I	53 50	6.50	5.25	1.50	1.50
10	900	M	75.00	13.25	7.85	2.00	2.50
10	1200	L	70.75	12.00	7.85	2.00	2.50
10	1800	J	59.50	7.00	6.60	1.75	2.00
15	720	P	93.75	15.50	10.25	3.00	4.00
15	900	N	71.25	14.25	10.25	3.00	4.00
15	1200	M	75.00	13.25	7.85	2.00	2.50
15	1800	K	73.75	8.75	8.05	1.75	2.00
20	600	S	156.25	19.00	12.10	3.25	6.00
20	900	P	93.75	15.50	10.25	3.00	4.00
20	1200	N	71.25	14.25	10.25	3.00	4.00
20	1800	M	75.00	13.25	7.85	2.00	2.50
25	600	S	156.25	19.00	12.10	3.25	6.00
25	720	S	156.25	19.00	12.10	3.25	6.00
25	900	R	143.75	17.75	12.00	3.25	6.00
25	1200	P	93.75	15.50	10.25	3.00	4.00
35	600	T	187.50	20.50	19.95	3.50	6.25
35	720	S	156.25	19.00	12.10	3.25	6.00
35	900	S	156.25	19.00	12.10	3.25	6.00
35	1200	R	143 75	17.75	12.00	3.25	6.00
50	600	V	218.75	21.75	30.85	3.50	6.25
50	720	V	218.75	21.75	30.85	3.50	6.25
50	900	T	187.50	20.50	19.95	3.50	6.25
50	1200	S	156.25	19.00	12.10	3.25	6.00

resoldering, as the case may be. However, this preliminary work is frequently necessary and must always be considered in making up estimates. It is due to a number of causes.

For example, the motor bearing linings may have worn down sufficiently to allow the rotor to rub against the stator. If the motor has operated very long in this condition the laminations of either or both stator and rotor will probably be damaged, which may require considerable work to put them into their original

condition. Again, a defective or broken bearing may injure the shaft. Sometimes this damage will be serious enough to require a new shaft. New bearing linings will probably be required in either case. Burned-out windings may also be accompanied by fusing of parts of the stator laminations. These fused portions must necessarily be removed before actual replacement of the coils can be commenced.

In a rotor which has been badly overheated, allowing the melted solder to be thrown out, arcing is frequently set up between the rotor bars and end rings, causing serious burning. When this occurs, new end rings are often needed, either for one or both ends of the rotor, or perhaps part of the bars will need to be replaced. With bolted end-ring construction there is also liability of trouble. The expansion of the end rings, caused by the excessive heat, tends to snap the bolts between the rotor bars and rings, producing the most favorable conditions for arcing. Burnouts of this kind, for either soldered or bolted construction, are quite common in connection with motors which have been started from time to time under loads requiring heavy starting torque with long periods of acceleration. Two or three-phase motors allowed to operate single-phase for any considerable length of time may also develop troubles of this nature. Very often the rotor will be badly damaged, while the stator has been only slightly overheated. Conversely, in some instances, the stator will be burned out, while the rotor is uninjured.

From these points it will be clear that estimates should not be made until after the motor has been given a careful inspection, otherwise there is likely to be a large discrepancy between the estimated and actual cost of the work. If an inquiry of this kind must be handled by letter it is not possible to make an inspection, but the dealer can at least detail clearly just what his estimate covers and point out the possibility of additional work that may be needed. Our readers will appreciate that estimates of this kind can be only approximately correct at the best. However, the table has been carefully compiled from data based upon a large number of actual repair jobs and it is believed these estimates will be found quite conservative.

Life of Wooden Stave Pipe. Data, August, 1915, says: The tabulation gives general data on the life of fir and redwood pipe under continuous water pressure. These data are summarized from statistics on 79 wooden pipe lines compiled by D. C. Henny, Consulting Engineer, United States Reclamation Service. Continuous stave and machine banded pipe are both considered.

Wood	Condition	Life, years
Fir	Uncoated, buried in tight soil	20
Fir	Uncoated, buried in loose soil	4–7
Fir	Uncoated, in air	12–20
Redwood	Uncoated, buried in tight soil, loam or sand, and gravel	Over 25
Fir	Well coated, buried in tight soil	25
Fir	Well coated, buried in loose soil	15–20

Cost of Maintaining Four Stokers and Furnaces for Six Years. The data in the accompanying table XIII taken from Electrical World, Dec. 16, 1916, show what it has cost a Middle West central station exclusive of labor charges to maintain four 10-ft. by 10-ft. chain-grate stokers and their furnaces during the six years they have been in service. It will be noted that the total expense for material has been $2,735.75 or an average of $114.99 per stoker per year. Of this amount $2,354.87 has been spent for tile and fireclay, while $400.88 has been spent for stoker parts,

TABLE XIII. COST OF STOKER AND FURNACE REPAIRS FOR SIX YEARS

	Cost of repairs		
	For stoker parts and iron parts or arch and feed gate	For tile and fireclay	Total
1910	$60.00	.....	$60.00
1911	14.00	$142.25	156.25
1912	61.12	823.17	884.29
1913	40.50	67.50	101.00
1914	3.00	217.00	220.00
1915	33.25	190.25	223.50
1916	189.01	894.70	1,083.71
	$400.88	$2,334.87	$2,735.75
Total per stoker per year	$16.70	$97.29	$114.99

and steel and iron parts of arches and feed gates. The cost per stoker per year for tile and fireclay was $97.29, and the cost per stoker per year for all castings and steel parts was $16.70. In other words, the cost of the tile and fireclay represented 85 per cent. of the total material maintenance cost.

A more detailed analysis of the cost of maintaining metal parts shows that the cost of replacing operating parts of the four stokers was but $8.77 per stoker per year, which is a very small percentage of $1,800, the present cost of such a unit without firebrick. Further study of data concerning the cost of the tile also shows that in 1912, when the maintenance cost was high, one complete 9.5-ft. by 6.5-ft. arch, and fifty large 4-in. by 12-in. by 24-in. bridge wall tile were purchased at a total cost of $498.22, which helped appreciably to increase the total for the year.

W. M. Duncan, vice-president of the Illinois Stoker Company, which supplied these units, in commenting on the data said that since the maintenance cost on the stokers has been so low — $8.77 per stoker per year — operating companies should not consider it a hardship if the concerns manufacturing such apparatus required the purchaser to keep repair parts in stock.

Cross References and References. Depreciation and repair data appear throughout this book, and can be found by use of the index under the name of each class of plant unit. Gillette's "Handbook of Cost Data," also his "Rock Excavation" and his "Earth Excavation," contain depreciation and repair data relating to construction machinery. Consult also Dana's "Handbook of Construction Plant."

CHAPTER III

BUILDINGS

The cost of a building is most easily estimated by the cubic foot of contents and the square foot of area, and such unit costs are frequently used and are of great value for preliminary estimates. For this reason the cost data in this chapter are for the most part based on these units, although the various functional costs such as bricklaying, concrete forms, carpentry, etc., are also discussed. The comparative costs and economy of various types of buildings are treated as well as complete costs of typical buildings. For further data on this subject the reader is referred to the following books: Cost Data, Earth Excavation and Rock Excavation by Halbert P. Gillette, Concrete Construction, Methods and Costs by Gillette and Hill and Construction Plant by R. T. Dana.

Economic Principles of Building Construction. The three principal elements that are essential to an economic investigation of a building problem are:

(1) The total cost of the structure, including the cost of the land that is necessary for it, or gross investment.

(2) The amount that can be borrowed on reasonable terms upon the completed structure, or the lien.

(3) The net periodic receipts that can reasonably be counted on. In any discussion of this kind, abnormal and accidental considerations must be eliminated from the problem. The owner is supposed to protect himself from loss by fire through fire insurance, and he must assume the risk from such accidents as he cannot protect himself against, such as earthquake, riots, wars, etc. The return that he receives upon his investment should be greater than the return that he can receive by investing his money in other ways free from those risks by an amount sufficiently greater to compensate him for the risk which he runs. If he can invest his money at 5% without risk it would be unwise for him to invest it at 5% in a building subject to uncompensated dangers. The so-called unearned increment upon his land, its conservative prospective increase in value from year to year, or from decade to decade, may be considered as offsetting to some degree various risks of loss. The depreciation in the value of the structure by age is something which can be computed and should be provided for in the computations by an estimated addition to the operating expense, this addition to be set aside in the form of an annuity toward a depreciation reserve.

The above mentioned three economic elements may each be sub-

divided into various factors, each of which is susceptible of individual investigation, and the combination for any particular case may be expressed for precision and convenience in an algebraic formula or by a combination of diagrams in such a manner that the bearing and influence of each factor or variations in any factor or combination of factors may be observed almost at a glance, to the end that we can solve a multitude of problems that are ordinarily complicated and complex, with surprising rapidity and without many of the uncertainties that invariably attend the study of such a problem when it is not divided into its principal factors.

In grouping the various elements of a problem of this kind so as to make them most amenable to study there are two principal methods, the first being to collect the several factors in groups of algebraic equations and the other by expressing them in diagrams. While it is often very helpful to say that one factor in a design is more important than another, the most desirable solution of such a problem requires one to be able to say how much more important it is. The solution, if possible, must be quantitative instead of qualitative; and this is the excuse, if one be needed, for introducing a considerable amount of algebra into the present subject. We have first to make a general solution containing what appear to be nearly all the principal factors involved and then by substituting in the equations the factors that belong to a large class of structures in a city such as New York to secure certain sub-general formulas in convenient form for use. Where an architect has a problem which meets the conditions and in which the factors have the values which have been assumed for these sub-general equations, he can use them directly; otherwise, he can substitute the factors that he finds common to his practice, and prepare sub-general equations and diagrams for himself.

* * Let L = The area of the lot occupied by the building in square feet.
* * S = " area of the building, in square feet.
* l = " ratio of building area to lot area.
* b = " ratio of rentable building area to total building area.
* R = " tax rate on full value.
* m = " ratio of the amount borrowed on mortgage to the total value.
* M = " rate of interest on the mortgage.
* v = " ratio of rented space to total rentable space.
* g = " ratio of overhead charges, commissions, etc., to gross receipts.
* f = " ratio of annual charges, superintendence, repairs, painting, general labor, insurance, fuel, lights, depreciation, etc., to total cost of the building.
* X = " ratio of net receipts to equity.
° C = " cost of the land per square foot in dollars.
° B = " cost of the building per square foot of floor area, in dollars.
° A = " annual gross rental per square foot of rented floor area, average in dollars.
° Y = " annual net receipts, in dollars.
n = " number of rentable stories in the building.
° F = " cost of the building per cubic foot.

$h =$ " average height of one story.
$S = Ll$
$B = Fh$

Units marked * * are areas.
Units marked * are ratios.
Units marked ° are in dollars.
Now, the capital investment will be CL for land, and
SnB for the building.
The total investment in dollars $= CL + SnB$
The amount placed on mortgage $= (CL + SnB)\ m$
The "Equity" or cost less the amount of the mortgage $= (CL + SnB)\ (1 - m)$

	Per year in dollars
The gross receipts will be........................	$AnSbv$
The operating expenses will be..................	$AnSbvg + SnBf$
The interest on the mortgage will be............	$Mm\ (CL + SnB)$
The taxes will be................................	$(CL + SnB)\ R$

Therefore, assuming that the total number of rentable stories equals the total number of stories,

$$(1) \quad Y = Sn\ [Abv\ (1 - g) - Bf] - (CL + SnB)\ (R + Mm)$$

$$(2) \quad \text{and } X = \frac{Y}{(CL + SnB)\ (1 - m)}$$

Now, $Ll = S$, and $L = \dfrac{S}{l}$

$$\therefore X = \frac{Y}{(C\dfrac{S}{l} + SnB)\ (1 - m)} = \frac{1}{S} \cdot \frac{Y}{(\dfrac{C}{l} + nB)\ (1 - m)}$$

Y may be written $=$

$$Sn\ [Abv\ (1 - g) - Bf] - S\ (\frac{C}{l} + nB)\ (R + Mm)$$

$$\therefore X = \frac{n\ [Abv\ (1 - g) - Bf] - (\dfrac{C}{l} + nB)\ (R + Mm)}{(\dfrac{C}{l} + nB)\ (1 - m)}$$

$$= \frac{n\ [Abv\ (1 - g) - Bf]}{(\dfrac{C}{l} + nB)\ (1 - m)} - \frac{(Mm + R)}{(1 - m)}$$

Finally,

$$(3) \quad X = \frac{Abv\ (1 - g) - Bf}{(\dfrac{C}{nl} + B)\ (1 - m)} - \frac{(Mm + R)}{(1 - m)}$$

All but four of the factors in this last equation represent ratios, and these four represent:

A — The rental per square foot of rented space, which depends upon the kind of building and the locality where it is erected.

B — The cost of the building per square foot of floor area, which depends upon the kind of building.

C — The cost of the land per square foot, which depends upon the locality.

n — The number of stories in the building.

The first three are functions of the locality and kind of building.

Y is a function of the times being 100% in periods of great prosperity and averaging in normal times 90%, more or less, depending upon the skill of the renting agent, the general desirability of the building, etc.

n, b and *l* are functions of the architect's design, together with *B*.

M and *m* are practically fixed functions, and *g* and *f* depend upon the kind of building and the purposes for which it is used.

Classification of Factors.— We may then say that the kind of building controls factors *A, B, g, f*.

The architect's design controls factors *n, b, l*, together with *B*.

The locality controls factor *C*.

And there are independent factors: *v, m, M, R*.

R in New York City is supposed to be about 1.8%. The city authorities try to assess property a little under its true value, but of late years the assessments in many sections have been over rather than under, the true amount. On a rising real estate market the assessments are generally too low, while on a falling one, the assessments are generally too high. For average conditions a fair value for *R* would be 1.75%

m — The percentage of the true value that can be borrowed on mortgage at 5% is generally nearly 66⅔%, so that *m* may be taken for average conditions at two-thirds, when *M* equals 5%.

l — The percentage of the total land area occupied by the building varies with the size of the building, the general plan of the architect's design, and the local conditions as to neighboring buildings, etc. The ruling conditions are light, air and architectural symmetry, and buildings on street corners are at a considerable advantage in this regard. Tall structures, with low adjoining buildings of a permanent nature are likewise at an advantage if it is reasonably certain that the adjoining property will not be built up. A 20-story building alongside of a 10-story one which is substantially built but with footings and columns designed for only ten stories is likely to enjoy an outlook over the roof of the ten-story one so long as the latter pays a fair return on its cost. At the best, however, there is a decided risk in counting upon such conditions for as many years as will represent the life of the modern steel or concrete building.

v —The percentage of efficiency in renting will very naturally vary with the times and conditions. It will never remain 100% for any great length of time, because when a section is fully rented at fair rates new construction and consequent competition is stimulated. Most real estate men consider that 10% for vacancies is a

fair value for a term of years. Therefore, we may take v as equal to 90%, or 0.9.

b — The percentage of the whole building space that brings a gross return, depends upon the space necessary for halls, stairways and elevators.

A — The rate per sq. ft. for ground floor rentals and that for upper floors varies in different sections of the city and also with the purposes for which the floors are used. Avenues generally rent higher than side streets, and retail buildings at higher rates than wholesale ones. In New York, and probably the same is true for most other large cities, the unit rentals on space for the most expensive luxuries are the highest, as, for example, jewelry and art showrooms, bric-a-brac shops of the most "exclusive" kind, millinery stores and haberdasheries. Space for banking and trust company buildings also comes high, and the rates for this purpose are very stable in comparison with those for mercantile purposes.

g — The percentage of gross rentals charged by agents for handling the property, negotiating leases, etc., ranges from 3% to 5%, with a general average of 4%.

h — The height of the average story in the commercial buildings that are built today varies a little, but will average from ten to twelve feet.

F — The cost of the building per cu. ft. will vary a good deal, depending upon the quality of the workmanship, the kind of construction, whether fireproof or not, the skill of the architect, the nature of the terms on which the building is erected and the credit of the builder. It depends also very largely on the skill of the engineer who supervises the layout of columns, etc., and upon the character of the ground underlying the foundations. A building in which the columns are uniformly spaced in one or both directions is very considerably less expensive than with irregular column spacing, owing to the lower cost of fabricating steel on a standardized design than on one of dissimilar sections. Moreover, with uniformity in the design the actual amount of steel in the frame is likely to be decidedly less than when irregular panels are employed. The same is largely true of reinforced concrete and composite structures. The building's height likewise affects the unit cost, because the taller it is the greater the column and footing loads, so that the cost of columns and footings is about proportional to the square of the number of stories to be carried, other conditions being equal. Since, however, the cost for beams, girders, floors, walls, ceiling, windows and door openings, etc., will be proportional to the cubic contents of the building, and these items in the aggregate are far in excess of the columns, footings and cellar excavation, it may be assumed for preliminary calculations that the cost of the building is nearly proportional to its volume. The location of the building must be carefully considered in the preliminary calculations, however. The "political" conditions, municipal regulations and street traffic all have much to do with the cost of erection.

f —The percentage of the original cost of the building consumed in annual charges will depend on the character of the service ren-

dered to tenants. This is high in office buildings and low in commercial ones and warehouses. The element of annual depreciation is one that depends on the life of the building and the rate at which a sinking fund can conveniently be invested.

Buildings-Factor Costs. Harold Green (Engineering and Contracting, Feb. 3, 1915) states that there is no fixed set of elements making up a land-and-buildings factor. In the majority of cases, however, the elements discussed below will include all the costs making up a complete factor for the purpose of a square foot distribution to departments or production centers as the cost-accounting practice may require. Thus the elements which have been selected are almost universal, while those particular to special industries are not considered. A classification of these elements together with an explanation of how the cost of each was determined follows:

(1) Fixed charges on land.
(2) Fixed charges on buildings.
(3) Fixed charges on building fixtures.
(4) Power and light.
(5) Heat.
(6) Building expense.

Costs of Elements. Fixed charges consist of interest, taxes, insurance, depreciation, and repairs, and these are calculated as a percentage of the appraisal value of the land, buildings, and fixtures. The interest rate was taken at 5 per cent. in all cases. Tax and insurance rates were determined for each particular case. These rates were quite uniform, however, and 1 per cent. for taxes and 0.5 per cent. for insurance would be fair averages. On buildings the rates for depreciation and repairs averaged 2 per cent. and 3 per cent. respectively, while for buildings fixtures, which consist of steam and water piping, electric light wiring, elevators, sprinkler systems, etc., rates of 5 per cent. for depreciation and 5 per cent. for repairs were used.

For convenience these rates are summarized in the following table:

	Land, per cent.	Buildings, per cent.	Fixtures, per cent.
Interest	5	5	5
Taxes	1	1	1
Insurance	..	0.5	0.5
Depreciation	..	2	5
Repairs	..	3	5
Total	6	11.5	16.5

It is evident that correct interest, tax, and insurance rates can be determined. Correct reserves for depreciation and repairs are open to considerable discussion, however, and the correct reserves will vary with the type of buildings under consideration. As a basis about 25 mill-construction buildings used for paper, textile, and machine-building industries, and costing from $1.25 to $1.50 per square foot, have been selected. The rates given above for

depreciation and repairs were used in these mills, and appear to be correct, judging from accumulated cost-accounting records.

The cost of the first three elements — fixed charges on land, buildings, and fixtures — was determined; then, by calculating proper annual interest, tax, insurance, depreciation, and repair charges as a percentage of the appraisal value of the land, buildings, and fixtures, the costs of these subdivisions were obtained.

The next two elements — power and light, and heat — include the cost of power used for lighting buildings and operating elevators, and the cost of steam used for heating. These costs are, of course, based on a determination of how much power and heat is used for these purposes, and how much it costs to make the power and steam in the particular plant.

The amount of steam used for heating was estimated theoretically by the same methods which would be used in designing a heating system for a mill building, and these theoretical results were checked with the known difference in coal consumption between winter and summer months due to heating. Power used for lighting was frequently developed by a separate generator, which enabled a log of switchboard readings to be used in making this determination. In a few cases power for lighting was purchased. Power used by elevators is, in most cases, a relatively small item and depends on the size of the elevators and the frequency with which they are used.

In determining the cost of the steam and power used, fixed charges on land, buildings, fixtures, and equipment, as well as operating charges for fuel, labor, supplies, etc., are included. In the several plants under discussion the average cost of steam was 30 cts. per 1,000 pounds, and of power 2 cts. per kilowatt hour. The cost of power, heat, and light was determined then by estimating the power, heat, and light used, and by calculating the cost, taking into consideration the cost of power at the plant in question.

The last element, buildings expense, is made up of expense items attendant upon the operation of practically all factory buildings. Under this head there has been included labor, such as watchmen, elevator operators, janitors, etc., and the cost of supplies used for cleaning buildings, the cost of water for general factory use, and other similar items.

Division of Costs. An attempt has been made in the preceding paragraphs to describe definitely how the total land-and-buildings factor has been determined. If this has been done, the data following should have a practical value for comparative purposes, and this discussion should serve as a basis for a study of buildings-factor costs with the object in view of approaching a maximum efficiency.

The average cost per square foot of floor space, in the buildings described above, and determined as explained in the previous paragraphs of this article, was 22 cts. As an illustration of the meaning of this cost, take the case of a boring mill in a machine shop which may occupy a space 20 ft. by 20 ft. when allowance is made for the machine, the operator, and the necessary movement of work at the machine. A square foot factor or buildings factor of, say 25 cts.

would mean that it costs $20 \times 20 \times 25$ cents, or $100 a year to house this machine. Assuming a working time of 2,500 hrs. a year, it would mean that this cost accumulates at a rate of 4 cts. an hr. This buildings-factor charge is an appreciable percentage of the wages paid the machine operator, and is but one of several equally important factors making up the total burden of the industry.

Relatively, the buildings-factor charge was found to be divided between the elements as follows:

Item.	Per cent.	Costs, cts. per sq. ft.
Fixed charges on land	10	2.2
Fixed charges on buildings	56	12.3
Fixed charges on buildings fixtures	9	2.0
Power and light	4	.9
Heat	14	3.1
Buildings expense	7	1.5
Total	100	22.0

Cost of Items of Buildings by Percentages. In any locality, if we select buildings of any given class and estimate the percentage of the total cost chargeable to each item, we find a remarkably small

	Frame buildings.	Brick residences.	Brick flats and stores.	Brick schools.	Brick Warehouses.	Machine shops (150 x 400).
Excavation, brick and cut stone	16%	36%	38%	48%	50%	15%
Plaster	8	6	6½	6	....	....
Skylights and glass	....	....	....	....	....	10
Millwork and glass	21	20	17	10½	7	6
Lumber	19	12	11½	11½	18½	6½
Carpenter labor	18	10	10	10	9½	4
Hardware	3½	3	2½	2½	....	....
Tin, galv. iron and slate	2½	4½	5	3½	....	1½
Gravel roofing	....	....	1½	....	2	1½
Structural steel	....	....	5½	....	....	45½
Steel lintels and hardware	....	....	....	....	8½	6
Plumbing and gas fitt'g	7	3	4	4	2	....
Piping for steam, water and power	....	....	....	....	....	2
Paint	5	5½	4½	4	2½	2
Total	100%	100%	100%	100%	100%	100%

Note.— Heating is not included.

variation. For example, the hardware item in brick residences averages about 3% of the total cost of the building whether the building costs $10,000 or $50,000. For a $10,000 building the hardware costs $\$10,000 \times 3\%$, or $300. For a $50,000 building, the hardware costs $\$50,000 \times 3\%$, or $1,500. In making preliminary estimates of cost it is often sufficiently close to estimate one or two of the large items and calculate the rest by percentages. Every builder and architect, therefore, should analyze the actual cost of

each item of a number of typical buildings, and reduce the analysis to percentages. Where foundation work is difficult and variable, it is well to exclude the foundations in forming a table of percentages, such as the one on this page. It is also well to carry the subdivisions of cost still farther; but for the purpose of example, the foregoing table serves to illustrate.

Cost of Miscellaneous Buildings. In the following tables by Leonard C. Wason of the Aberthaw Construction Co. given in Engineering Record, Feb. 27, 1909, in each case the total cost includes masonry and carpentry work without interior finish or decorating, plumbing and heating. The effort has been made to put the buildings upon a comparative basis as regards the amount of work done on each.

The first table consists of the total cost of actual contracts executed. The second table consists of bona fide bids on complete

TABLE I. COST OF FIREPROOF COMPLETED BUILDINGS

Kind of building.	Volume in cu. ft.	Floor area in sq. ft.	Unit cost Per cu. ft.	Unit cost Per sq. ft.
Offices and stores....	1,365,830	90,474	$0.133	$2.00
Offices and stores....	496,780	39,840	.124	1.545
Factory	112,440	7,519	.114	1.70
Factory	746,674	49,546	.060	.902
Factory	312,000	24,960	.127	1.60
Garage	156,198	10,806	.085	1.23
Filter	149,250	19,208	.134	1.04
Fire station	44,265	2,982	.153	2.26
Observatory	9,734	657	.373	5.45
Filter	59,991	5,243	.333	3.82
Highest	....	....	.333	3.82
Lowest	....	....	.06	.90
Average	....	....	.138	1.72

buildings on which Mr. Wason's company were not the lowest bidders but where the difference was not as a rule very great. The third and fourth tables are bona fide bids on work by another contractor whose experience was similar to that of Mr. Wason's. As a rule, cubic foot measurements are given in cents only, seldom being carried to any closer sub-division. In the table on second class buildings, it will be noted that for the largest building a variation of 1 cent per cubic foot amounts to over $28,000, while the smallest one in the list amounts to only a little over $5,400. Again, on the last three items, the cubic foot price is practically identical, while the square foot measurements corresponding vary by more than 100 per cent. with no easily apparent reason in the design.

In the table on fireproof buildings another discrepancy is noticed. In the first and last items, the highest and the lowest per cubic foot as well as per square foot are on office buildings of similar type which were within one mile of each other where there is no apparent reason for such discrepancy in the design or difficulty of access in the erection of the building. It is recommended by Mr. Wason that very little reliance be placed upon this class of estimates.

TABLE II. COST OF FIREPROOF COMPLETE BUILDINGS

Kind of building.	Volume in cu. ft.	Floor area in sq. ft.	Unit cost Per cu. ft.	Unit cost Per sq. ft.
Storehouse	1,714,448	168,696	$0.0827	$0.84
Hospital	703,692	57,654	.0865	1.05
Office building	496,780	39,840	.124	1.545
Cold storage	1,535,000	154,000	.13	1.30
Factory	212,400	15,000	.091	1.28
Factory	1,327,868	106,022	.107	1.335
Storehouse	1,140,000	146,000	.0685	.575
Mfg. building	1,380,500	90,240	.067	1.01
Office	693,840	56,552	.197	2.42
Factory	105,600	8,800	.124	1.485
Factory	1,211,364	74,604	.0625	1.01
Factory	180,000	16,394	.129	1.42
Highest	....	....	.197	2.42
Lowest	....	....	.0625	.575
Average	....	....	.1088	1.27

TABLE III. COST OF FIREPROOF BUILDINGS

Kind of building.	Volume in cu. ft.	Floor area in sq. ft.	Unit cost Per cu. ft.	Unit cost Per sq. ft.
Office building	441,000	35,854	$0.159	$1.97
Cold storage	1,016,400	101,640	.13	1.30
Hospital	348,320	34,832	.127	1.27
Hospital	414,732	29,838	.124	1.73
Bank	533,750	....	.123	....
Masonic	1,479,456	....	.122	....
Warehouse	259,700	24,500	.120	1.28
Garage	497,420	....	.118	....
Warehouse	2,597,000	212,000	.106	1.30
Hotel	2,116,106	....	.104	....
Hospital	485,789	38,247	.100	1.30
Office	264,687	....	.095	....
Cold storage	909,240	66,745	.091	1.24
Club	513,808	....	.085	....
Office	501,575	67,400	.084	1.12
Highest	....	....	.159	1.97
Lowest	....	....	.084	1.12
Average	....	....	.113	1.39
Variation, high and low	....	....	53.8%	57.0%

TABLE IV. COST OF MILL CONSTRUCTION OR SECOND-CLASS BUILDING

Kind of building.	Volume in cu. ft.	Floor area in sq. ft.	Unit cost Per cu. ft.	Unit cost Per sq. ft.
Mill	544,788	44,172	$0.122	$1.51
Warehouse	2,808,850	....	.12	....
Mill	1,271,300	129,920	.0891	.875
Storehouse	1,714,448	168,696	.059	.60
Mill	1,622,128	152,200	.056	.60
Mill	1,331,200	83,200	.054	.865
Mill	1,752,609	81,500	.048	1.05
Mill	2,641,000	98,059	.046	1.25
Mill	2,036,731	174,000	.046	.542
Mill	2,867,535	157,730	.045	.82
Highest	....	....	.122	1.51
Lowest	....	....	.045	.542
Average	....	....	.069	.90

Table V was condensed from data given by F. E. Kidder in Building Construction.

TABLE V. COST PER CUBIC FOOT FOR VARIOUS HEIGHTS

Type of bldg. and construction.	No. Incl.	No. of stories Max.	Min.	Avg.	Cost per cu. ft. Max.	Min.	Avg.
Office buildings:							
Fireproof	21	20	2	9.35	63c	25c	41.5c
Non-fireproof .	3	12	3	7.66	36.4	19	27.13
Warehouses:							
Fireproof	2	7	5	6	25.17	17.12	21.14
Non-fireproof .	1	7	7	7	9.08	9.08	9.08
Stores:							
Fireproof	2	6	4	5	31	29	30
Non-fireproof .	1	8	8	8	19.75	19.75	19.75
Hotels and apartment houses:							
Fireproof	4	14	7	9.5	44	30	38.8
Non-fireproof .	1	5	5	5	18.5	18.5	18.5

F. J. T. Stewart states that in 1906 the average cost of three fireproof office buildings in Chicago was 33 cts. per cu. ft., while that of four fireproof office buildings in Boston was 40 cts. per cu. ft.

Cost of Office Buildings. Building Management gives the following table of approximate average cost, in cents, per cubic foot of content of buildings, for the principal items of a first-class office building, as compiled from costs of numerous buildings.

Item.	Cost, per cu. ft., in cts.
Foundation	1.75
Steel framing	2.50
Granite and all masonry	11.17
Cornice, roof and skylights	0.67
Fireproof floors	0.67
Partitions, tile	0.40
All plastering and stucco	1.25
Ornamental metal work	2.00
Marble work	3.17
Hardware	0.13
Joiner work	1.17
Glass	0.42
Painting and varnish	0.23
Electric wiring	0.66
Heating	1.12
Plumbing	0.50
Elevators	1.00
Stairs, scenic structural framing, lamp fixtures, etc., "contingencies," including lesser items not mentioned above	4.19
Architect's fee	2.60
Total cost per cu. ft.	34.42

Comparative Cost of Wood and Steel Frame Factory Buildings. H. G. Tyrrell gives the following, based on prices existing in Ohio in the forepart of 1905.

Slow Burning Wood Construction. The building is 60 x 100 ft., six stories high, containing 6 floors, a roof and a cellar. The floors

are designed for a load of 100 lbs. per sq. ft. The building has windows on all four sides. The walls (brick) carry the ends of the floor beams. The basement walls are 24 ins. thick. Walls of first four stories are 17 ins. thick; top two stories, 13 ins. thick. Eight tiers of columns, spaced 20 ft. apart in both directions, carry the floors and roof. The columns of the upper four stories are yellow pine, the size being 14 x 14 ins. for the lowest of these four stories. Below this, round cast iron columns are used, 11 x 1¼ ins. in the first story, and 12 x 1½ ins. in the basement. All columns have cast iron bases 3 ft. square and 16 ins. high. Lengthwise through the building in the floors, run two lines of 12 x 20-in. yellow pine header beams resting on the brackets of the cast iron column caps. The cross floor beams are 8 x 16-in. yellow pine, spaced 5 ft. apart. At the columns they rest on column caps, and at intermediate points they hang from the header beams by wrought iron stirrups. In the walls the cross beams rest on cast iron wall plates, 9 x 20 x ¾ in. The floor is of ⅞-in. matched maple, laid on 1¾-in. yellow pine. The roof is similar in construction and has a tar and gravel covering.

The following estimates are for the structural part of the building only, including walls, columns, floors, roof, excavation, foundation, doors and windows, but not including partitions, stairs, elevators, plumbing, heating, lighting or wiring.

1. Excavation (cu. yds.)	1,800
2. Cellar cement floor (sq. ft.)	6,000
3. Foundation concrete (cu. yds.)	150
4. Brick (cu. ft.)	39,000
5. Windows, 4 x 7 ft.	238
6. Roofing (sq. ft.)	6,000
7. Yellow pine timber (M.)	116
8. Yellow pine flooring (M.)	73
9. Matched flooring (M.)	46
10. Iron work (tons)	46

The estimated cost of this design is $35,000, which is equivalent to 6.1 cts. per cu. ft., or 83 cts. per sq. ft. of entire floor area.

The interior framing of floors and columns (including wall plates, columns, caps and bases and stirrup irons), is 27 cts. per sq. ft. of floor area.

Fireproof Steel Construction. This is similar in design to the above, as regards arrangement of beams and columns. Riveted steel columns are used, and the floors are framed with steel beams. The flooring between the beams is reinforced concrete.

The quantities are as before for items (1) to (6) inclusive. The remaining items are:

7. Steel columns (tons)	105
8. Steel beams and wall plate (tons)	252
9. Concrete floor and roof (sq. ft.)	42,000

The estimated cost is $57,000, which is equivalent to 10.2 cts. per cu. ft., or $1.36 per sq. ft. of total floor area. Floors and columns cost 75 cts. per sq. ft. of floor area, as compared with 27 cts. for the slow burning mill construction.

Cubic Foot Costs of Reinforced Concrete Buildings.*— The following costs are for buildings actually erected and they are given by Emile G. Perrot, M. Am. Soc. C. E.:

	Cents per cu. ft.
Warehouses and manufactures	8 to 10
Stores and loft buildings	11 to 17
Miscellaneous, such as schools and hospitals..	15 to 20

These costs include the building complete, omitting power, heat, light, elevators and decorations or furnishings.

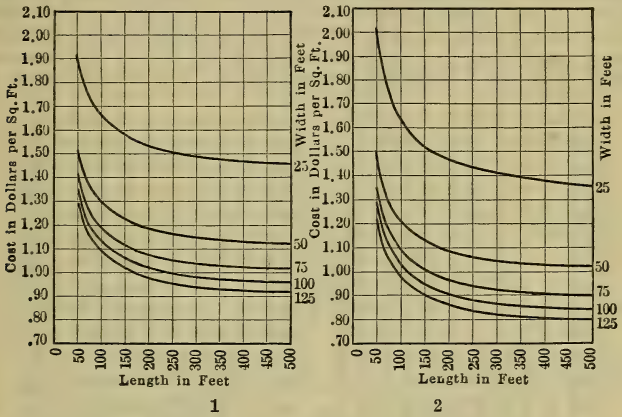


Fig. 1. Diagram showing estimated cost per sq. ft. of floor area for one story brick buildings for textile manufacturing.

Fig. 2. Diagram showing estimated cost per sq. ft. of floor area for two-story brick buildings for textile manufacturing.

Cost of Mill Buildings. (Engineering and Contracting, Jan. 27, 1909.) Charles F. Main is authority for the following data, based upon eastern prices in 1910.

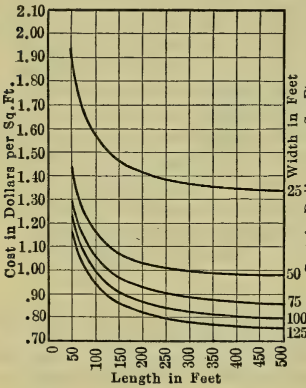
It is not an uncommon thing to hear the cost of mill buildings placed from 70 cts. to $1 per sq. ft. of floor space, regardless of the size or number of stories. There is, however, a wide range of cost per square foot of floor space, depending upon the width, length, height of stories and number of stories.

Some time ago, I placed a valuation upon a portion of the property of a corporation, including some 400 or 500 buildings. In order to have a standard of cost from which to start in each case, I prepared a series of diagrams showing the approximate costs of buildings varying in length and width and from one story to six stories in height. The height of stories also was varied for different widths, being assumed 13 ft. high if 25 ft. wide, 14 ft. if 50 ft. wide, 15 ft. for 75 ft., 16 ft. for 100 ft. and over.

* Engineering and Contracting, Jan. 27, 1909.

The costs used in making up the diagrams are based largely upon the actual cost of work done under average conditions of cost of materials and labor and with average soil for foundations. The costs given include plumbing, but no heating, sprinklers, or lighting. These three latter items would add roughly 10 cts. per sq. ft. of floor area.

Estimates. The accompanying diagrams, Figs. 1 to 6, can be used to determine the probable approximate cost of proposed brick buildings, of the type known as "slow-burning" to be used for manufacturing purposes, with a total floor load of about 75 lbs. per sq. ft. and these can be taken from the diagrams readily. The curves were derived primarily to show the estimated cost per square foot of gross floor area of brick buildings for textile mills, and to include ordinary foundations and plumbing. For example, if it is



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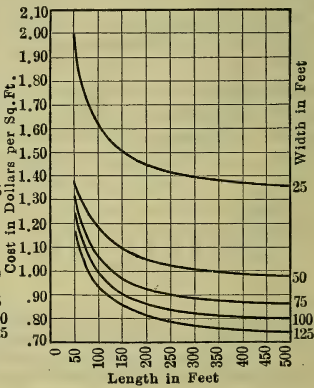

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Fig. 3. Diagram showing estimated cost per sq. foot of floor area for three-story brick buildings for textile manufacturing.

Fig. 4. Diagram showing estimated cost per sq. ft. of floor area for four-story brick buildings for textile manufacturing.

desired to know the probable cost of a mill 400 ft. long by 100 ft. wide, three stories high, refer to the curves showing the cost of three-story buildings. On the curve for buildings 100 ft. wide, find the point where the vertical line of 400 ft. in length cuts the curve, then move horizontally along this line to the left-hand vertical line, on which will be found the cost of 81 cts.

The cost given is for brick manufacturing buildings under average conditions and can be modified if necessary for the following conditions:

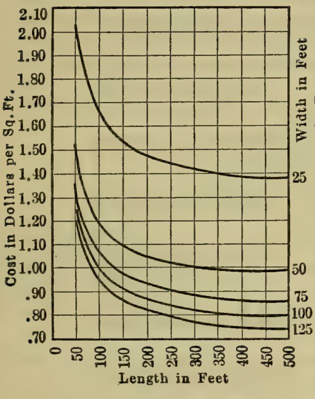
(a) If the soil is poor or the conditions of the site are such as to require more than the ordinary amount of foundations, the cost will be increased.

(b) If the end or a side of the building is formed by another building, the cost of one or the other will be reduced slightly.

(c) If the building is to be used for ordinary storage purposes with low stories and no top floors, the cost will be decreased from about 10% for large low buildings, to 25% for small high ones, about 20% usually being a fair allowance.

(d) If the buildings are to be used for manufacturing purposes and are to be substantially built of wood, the cost will be decreased from about 6% for large one-story buildings, to 33% for high small buildings; 15% would usually be a fair allowance.

(e) If the buildings are to be used for storage with low stories and built substantially of wood, the cost will be decreased from 13%



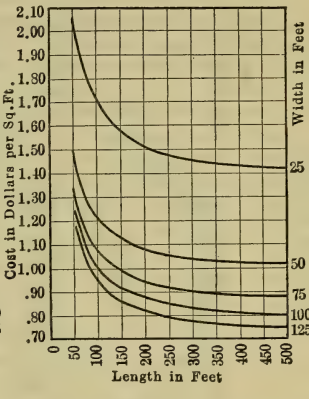


Fig. 5. Diagram showing estimated cost per sq. ft. of floor area for five-story brick buildings for textile manufacturing.

Fig. 6. Diagram showing estimated cost per sq. ft. of floor area for six-story brick buildings for textile manufacturing.

for large one-story buildings, to 50% for small high buildings; 30% would usually be a fair allowance.

(f) If the total floor loads are more than 75 lbs. per sq. ft. the cost is increased.

(g) For office buildings, the cost must be increased to cover architectural features on the outside and interior finish.

The cost of very light wooden structures is much less than the above figures would give. Table VI shows the approximate ratio of the costs of different kinds of buildings to the cost of those shown by the curves.

Evaluations. The diagrams can be used as a basis of valuation of different buildings.

A building, no matter how built nor how expensive it was to build, cannot be of any more value for the purpose to which it is

TABLE VI. RATIO OF COST OF VARIOUS BUILDINGS TO THAT OF BRICK MILLS, STANDARD CONSTRUCTION

Superficial feet of floor in 1 sty.	Frame Mills						Brick Store House.						Frame Store House.					
	1 Sto.	2 Sto.	3 Sto.	4 Sto.	5 Sto.	6 Sto.	1 Sto.	2 Sto.	3 Sto.	4 Sto.	5 Sto.	6 Sto.	1 Sto.	2 Sto.	3 Sto.	4 Sto.	5 Sto.	6 Sto.
1,250	.86	.67					.80	.73					.70	.51				
2,500	.86	.73					.85	.73					.75	.58				
5,000	.89	.78	.75	.73	.70	.67	.83	.80	.78	.76	.76	.75	.74	.60	.56	.53	.51	.48
7,500	.90	.79	.77	.74	.71	.69	.85	.81	.78	.77	.76	.76	.77	.63	.58	.55	.53	.51
10,000	.90	.80	.78	.75	.73	.70	.87	.81	.79	.78	.77	.76	.78	.65	.60	.57	.55	.53
15,000	.91	.82	.79	.77	.75	.72	.89	.83	.81	.79	.78	.78	.81	.67	.64	.61	.59	.56
20,000	.92	.83	.81	.79	.77	.74	.90	.84	.82	.80	.80	.79	.82	.70	.67	.64	.61	.59
25,000	.92	.85	.82	.80	.78	.76	.91	.85	.83	.82	.81	.80	.83	.72	.69	.66	.63	.61
30,000	.93	.86	.84	.81	.80	.77	.91	.86	.84	.82	.81	.81	.84	.73	.70	.67	.65	.62
35,000	.93	.87	.84	.82	.80	.78	.92	.86	.84	.83	.82	.81	.85	.74	.71	.68	.66	.63
40,000	.93	.87	.85	.83	.81	.79	.92	.87	.85	.84	.83	.82	.86	.75	.72	.69	.67	.64
45,000	.94	.87	.85	.83	.82	.79	.92	.87	.85	.84	.83	.82	.86	.76	.72	.70	.67	.65
50,000	.94	.88	.86	.84	.82	.80	.92	.88	.86	.84	.83	.83	.87	.77	.73	.71	.69	.66

put than a modern building properly designed for that particular purpose. The cost of such a modern building is then the limit of value of existing buildings. Existing buildings are usually of less value than new modern buildings for the reason that there has been some depreciation due to age and that the buildings are not as well suited to the business as a modern building would be.

Starting with the diagrams as a base, the value can be approximately determined by making the proper deductions.

The diagrams can be used as a basis for insurance valuations after deducting about 5% for large buildings to 15% for small ones, for the cost of foundations, as it is not customary to include the foundations in the insurable value.

Use of Tables. Table VII shows the costs which form the basis of the estimates and these unit prices can be used to compute the cost of any building not covered by the diagrams. The cost of brick walls is based on 22 bricks per cubic foot, costing $18 per

TABLE VII. DATA FOR ESTIMATING COST OF BUILDINGS

	Foundations including exc. Cost per lin. ft. for outside walls.	inside walls	Brick walls. Cost per sq. ft. of surface. outside walls.	for inside walls.	Columns including piers and castings. Cost of one.
One-story building......	$2.00	$1.75	$ .40	$ .40	$15.00
Two-story building.....	2.90	2.25	.44	.40	15.00
Three-story building....	3.80	2.80	.47	.40	15.00
Four-story building.....	4.70	3.40	.50	.43	15.00
Five-story building.....	5.60	3.90	.53	.45	15.00
Six-story building......	6.50	4.50	.57	.47	15.00

thousand laid. Openings are estimated at 40 cts. per sq. ft., including windows, doors and sills.

Ordinary mill floors, including timbers, planking and top floor with Southern pine timber at $40 per M. ft. B. M. and spruce planking at $30 per M., costs about 32 cts. per sq. ft., which has been used as a unit price. Ordinary mill roofs covered with tar and gravel, with lumber at the above prices, cost about 25 cts. per sq. ft. and this has been used in the estimates. Add for stairways, elevator wells, plumbing, partitions and special work.

Deductions from Diagrams. (1) An examination of the diagrams shows immediately the decrease in cost as the width is increased. This is due to the fact that the cost of the walls and outside foundations, which is an important item of cost, relative to the total cost, is decreased as the width increases.

For example, supposing a three-story building is desired with 30,000 sq. ft. on each floor:

If the building were 600 ft. x 50 ft., its cost would be about 99 cts. per sq. ft.

If the building were 400 ft. x 75 ft., its cost would be about 87 cts. per sq. ft.

If the building were 300 ft. x 100 ft., its cost would be about 83 cts. per sq. ft.

If the building were 240 ft. x 125 ft., its cost would be about 80 cts. per sq. ft.

(2) The diagram shows that the minimum cost per square foot is reached with a four-story building. A three-story building costs a trifle more than a four-story. A one-story building is the most expensive. This is due to a combination of several features:

(a) The cost of ordinary foundations does not increase in proportion to the number of stories, and therefore their cost is less per square foot as the number of stories is increased, at least up to the limit of the diagram.

(b) The roof is the same for a one-story building as for one of any other number of stories, and therefore its cost relative to the total cost grows less as the number of stories increases.

(c) The cost of columns, including the supporting piers and castings, does not vary much per story as the stories are added.

(d) As the number of stories increases, the cost of the walls, owing to increased thickness, increases in a greater ratio than the number of stories, and this item is the one which in the four-story building offsets the saving in foundations and roof.

(3) The saving by the use of frame construction for walls instead of brick is not as great as many persons think. The only saving is in somewhat lighter foundations and in the outside surfaces of the building. The floor, columns, and roof must be the same strength and construction in any case.

TABLE VIII. DATA FOR APPROXIMATING COST OF MILL BUILDINGS OF KNOWN SIZE BUT WITHOUT DEFINITE PLANS MADE

	Foundations, including exc. Cost per lin. ft.		Brick walls Including doors and windows. Cost per sq. ft. of surface.	
Height of building.	for outside walls.	inside walls.	outside walls.	for inside walls.
One story......	$2.00	$1.75	$ .40	$ .40
Two stories....	2.90	2.25	.44	.40
Three stories...	3.80	2.80	.47	.40
Four stories....	4.70	3.40	.50	.43
Five stories....	5.60	3.90	.53	.45
Six stories.....	6.50	4.50	.57	.47

Assumed Height of Stories. From ground to first floor, 3 ft. Buildings 25 ft. wide, stories 13 ft. high. Buildings 50 ft. wide, stories 14 ft. high. Buildings 75 ft. wide, stories 15 ft. high.. Buildings 100 ft. wide, stories 16 ft. high. Buildings 125 ft. wide, stories 16 ft. high.

Unit Prices. Floors, 32 cts. per sq. ft. of gross floor space not including columns. If columns are inclined, 38 cts.

Roof, 25 cts. per sq. ft., not including columns. If columns are included, 30 cts. Roof to project 18 ins. all around buildings.

Stairways, including partitions, $100 each flight. Allow two stairways, and one elevator tower for buildings up to 150 ft. long. Allow two stairways and two elevator towers for buildings up to

TABLE IX. COST OF REINFORCED-CONCRETE INDUSTRIAL BUILDINGS

Type.	Size, ft.	Stories. No.	Stories. Height, ft.	Live load, lbs. per sq. ft.	Kind of floor.	Column spacing, ft.	Costs per sq. ft.	Costs per cu. ft.
Machine shop....	50 by 120	4	12.0	150	Beam and slab....	10 by 24	$1.17	$ .09
Cotton mill	129 by 550	2	16	75	Beam and slab....	10.8 by 25	.98	.07
....	....	4	12.6	150	Flat slab.........	17 by 20	1.09	.077
Weave mill	60 by 140	5	12.6	150	Flat slab.........	17.6 by 20	1.50	.12
Knitting mill.....	75 by 220	2	14	125	Beam and slab....	12 by 25	1.09	.073
Factory	56 by 223	2	16	300	Beam and slab....	18.6 by 18.6	1.55	.10
Weave shed......	231 by 341	1	..	125	Saw tooth........	13 by 21.4	1.79	.07
Machine shop....	100 by 220	1	..	...	....	20 by 20	1.75	.10
Storehouse	56 by 181	4	14.6	150	Flat slab.........	18 by 20	1.15	.07
Storehouse	109 by 580	10	12	250	Beam and slab....	19.3 by 19	.85	.071
Storehouse	....	..	..	...	....	....	.76	.05
Storehouse	100 by 256	12	8	150	Flat slab.........	16 by 16.8	1.04	.12

300 ft. long. In buildings over two stories, allow three stairways and three elevator towers for buildings over 300 ft. long.

In buildings over two stories, plumbing $75 for each fixture including piping and partitions. Allow two fixtures on each floor up to 5,000 sq. ft. of floor space and add one fixture for each additional 5,000 sq. ft. of floor or fraction thereof.

(Note. From the above data the approximate cost of any size and shape of building can be estimated in a few minutes. After the cost of the items given is determined about 10% should be added for incidentals.)

Reinforced Concrete Buildings. From such estimates and proposals as I have been able to get and from work done it appears that the cost of reinforced concrete buildings designed to carry floor loads of 100 lbs. per sq. ft. or less would be about 25% more than the slow-burning type of mill construction.

Alternate Method of Estimating Cost. Floors. 38 cts. per sq. ft. of gross floor space. This price will include column piers, column castings and wrought iron.

Roof. 30 cts. per sq. ft., including projections, say 18 ins., including columns, etc.

Stairways and Elevator Towers. Allow two stairways and one elevator tower in buildings over two stories high up to 150 ft. long. Allow two stairways and two elevator towers up to 300 ft. long. Allow three stairways and three elevator towers over 300 ft. long.

Brick Walls. Enclosing stairs and elevators, estimated as inside walls.

Stairs. $100 per flight, per story.

Plumbing. Allow two fixtures on each floor up to 5,000 sq. ft. of floor space, and add one fixture for each additional 5,000 sq ft. or fraction thereof. Allow $75 per fixture.

Incidentals. Add about 10% for incidentals.

Cost of Buildings of Wood, Concrete, and Steel Framing. H. G. Tyrrell (Engineering Magazine, June, 1912), gives the following data, Table IX, presented at the convention of the National Association of Cement Users in 1912:

From this table it appears that the average cost of single-story buildings with saw-tooth roof is $1.77 per sq. ft. of floor and 8½ cts. per cu. ft. of contents, while the average cost of buildings with more than one story is $1.12 per sq. ft. of floor and 8.7 cts. per cu. ft. of contents. These figures are on the complete building with plumbing, but they do not include heating, lighting, sprinkler system, elevators, or power equipment. The square-foot prices were obtained by dividing the total cost of the building by the aggregate floor area including the basement, but not including the roof.

Another report on the cost of reinforced-concrete buildings read in 1909 before the National Association of Cement Users gives the specific costs of 21 buildings, showing an average cost of $1.72 per sq. ft. of floor area and 13.8 cts. per cu. ft. of contents, as given in Table X.

It appears therefore that the average cost of forms per square foot is for columns 13 cts., beam floors 11.6 cts., slab floors 11.1 cts.,

TABLE X. COST OF CONCRETE BUILDINGS

Type.	Volume in cu. ft.	Floor area, sq. ft.	Costs. cu. ft.	sq. ft.
Store	1,714,400	168,696	$ .0827	$ .84
Hospital	703,692	57,654	.0865	1.05
Office	496,780	39,840	.124	1.545
Cold storage	1,535,000	154,000	.13	1.30
Factory	212,400	15,000	.091	1.28
Factory	1,329,868	106,000	.107	1.335
Storehouse	1,140,000	146,000	.0685	.575
Factory	1,380,500	90,240	.067	1.01
Office	693,840	56,552	.197	2.42
Factory	105,600	8,800	.124	1.485
Factory	1,211,364	75,604	.0625	1.01
Factory	180,000	16,394	.129	1.42
Office	1,365,800	90,474	.133	2.00
Factory	112,440	7,519	.114	1.70
Factory	746,674	49,546	.060	.902
Factory	312,000	24,960	.127	1.60
Garage	156,198	10,806	.085	1.23
Filter	149,250	19,208	.134	1.04
Fire station	44,265	2,982	.153	2.26
Observatory	9,734	657	.373	5.45
Filter	59,991	5,243	.333	3.82
Average			$ .138	$1.72

slabs only between steel beams 9.5 cts., walls above ground 12.8 cts., foundations 10.3 cts. and footings 9.3 cts.

A subdivision giving the percentage cost of concrete, steel, labor and forms is as follows:

	Per cent. of total.
Concrete	19
Steel	17
Labor	31
Forms	33
Total	100%

This analysis assumes that materials can be delivered at the site on cars, and that form lumber can be used twice. As two-thirds of the total cost is for labor and forms, and one-third for the forms alone, it is economical, where time will permit, to use forms more than twice, or as often as the lumber will last. Repetition and duplication of forms are in fact the greatest factors in cost reduction, and the design should be so made that this is possible. The average cost of forms obtained from a different set of records from those given above, is, for floors with beams, girders and slabs, 10 cts. per square foot, and for slab floor without beams 7 cts. per square foot. The corresponding cost of column forms is 13 cts. per square foot. The cost of bending and placing reinforcing steel, including wire mesh in slabs, varies from $5 to $17 per ton, the average being about $10 per ton.

A reinforced-concrete building designed by the writer, 55 ft. wide and 88 ft. long, with seven stories and basement and 500,000 cu. ft. of contents, cost $1.15 per square foot of floor, or 9.1 cts. per cu. ft. of contents. The floors were proportioned for a total load of 200 lbs. per sq. ft. and the prices given above include excavation, foun-

TABLE XI. COST ANALYSIS OF FORMS AND CONCRETE; AVERAGE RESULTS

	Cost of forms per sq. ft. of surface.				Cost of concrete per cu. ft. in place.						
	Labor.	Lumber.	Nails.	Total.	Concrete labor.	General labor.	Cement.	Aggregate.	Teaming.	Plant.	Total.
Columns	$ .082	$ .036	$ .001	$ .130	$ .096	$ .027	$ .085	$ .049	$ .021	$ .023	$ .301
Beam floors	.070	.045	.002	.116	.111	.020	.106	.063	.025	.024	.354
Slab floors	.071	.038	.002	.111	.097	.009	.096	.070	.019	.024	.315
Slabs only	.061	.032	.002	.095	.102	.019	.128	.068	.024	.017	.359
Walls	.085	.036	.002	.128	.090	.016	.073	.076	.025	.019	.301
Foundation	.068	.033	.002	.103	.076	.015	.080	.062	.019	.017	.269
Footings	.057	.034	.002	.093	.045	.007	.071	.077	.007	.021	.229

dations, walls, columns, floors, framing, roofing, windows, doors and stairs, but do not include plumbing, elevators, heating, lighting or partitions.

Concrete factory buildings from one to five stories in height and about 50 ft. wide will have minimum costs about as follows:

	Cost per sq. ft. of floor area.	Costs in cents per cu. ft. of contents.
3, 4 and 5 stories......	$1.00 to $1.10	7.5 to 8.5
2 stories	1.05 to 1.15	8.0 to 9.0
1 story	1.10 to 1.20	8.5 to 10.0

These prices do not include partitions, plumbing, heating, lighting or elevators. In the Southern States or in country districts where labor is cheaper, the unit costs may occasionally be 10 to 15 per cent. less. But when buildings are erected by contractors who are only occasionally employed on such work, the cost is likely to exceed the minimum prices given above, and amount to $1.30 per sq. ft. for buildings of three stories or more, to $1.60 per sq. ft. for those with only single stories. Concrete framing, including slabs, beams and columns only, without walls, costs from 45 to 65 cts. per sq. ft. of floor area.

The cost of reinforced-concrete buildings from numerous designs varies from 6 to 12 cts. per cu. ft. for factories and warehouses, and from 10 to 16 cts. per cu. ft. for stores and loft buildings. These are based upon the use of complete concrete frames and exterior curtain walls, without power, heat, light, elevators or interior finish. Buildings with concrete slabs and 2-inch cement finish, costing $1.25 per square foot, would with cement finish on 2-in. cinder concrete cost about $1.30 per square foot with ⅞-in. maple on 2-in. cinder concrete, with a concrete floor slab in each case.

A two-story reinforced-concrete factory building 100 ft. square, at Walkerville, Ontario, with 6-in. curtain walls, and columns 16-ft. apart in both directions, cost complete, including concrete, rods, and forms, $19.88 per cubic yard of concrete in place.

Some contractors used the following method of estimating the cost per cubic yard of all the material in place. First find the cost delivered at the site, of the cement, sand and stone required for a cubic yard of concrete, and to this add $5 per yard for the reinforcing metal. The sum of these two costs is assumed to represent one-half of the total cost per cubic yard of the materials in place. The labor of mixing and placing the concrete and of placing the steel will add one-third to the above sum, and the material and labor on forms will be two-thirds more. The resulting cost does not include contractors' profit or plant depreciation. General expense and cleaning up after completion may be $1 to $2 per cu. yd. additional.

A considerable saving in the cost of reinforced-concrete buildings can be effected by omitting the floor slabs, and using a frame of columns and girders only, with a double course of boards supported on reinforced-concrete beams. For specific example, a four-

story office building of this kind at Fore River, Mass., a large part of the curtain walls being glass, cost with the foundations, walls, roof, and floors, only 63 cts. per sq. ft. of floor area, or 4½ cts. per cu. ft. of contents. Including lighting, heating, toilets, and partitions, the cost was $1.30 per sq. ft. of floor, or 9.2 cts. per cu. ft. Another similar five-story building in the same state, 50 by 300, cost only 7.6 cts. per cu. ft.

Economy often results, also, from the use of separately moulded floor members, a good example being the cold-storage warehouse at Syracuse, recently constructed. The building was six stories high and 78 ft. square, and concrete floors of the Watson system were supported by a frame of steel beams and columns. The floors alone cost 20.5 cts. per sq. ft., and the steel frame and fireproofing 21.5 cts. additional, or a total of 42 cts. per sq. ft. of floor area, or 4 cts. per cu. ft. of volume for both floor and frame. Including the gravel roof, curtain walls, and stairs, the cost was 61 cts. per sq. ft, or 5.7 cts. per cu. ft., the granolithic floor finish, and wall plastering not being included. In determining these unit prices, the area of six floors and basement was taken inside of the exterior walls.

Much of the published information in reference to the cost of concrete work is based upon the records of well organized building companies who are equipped to do such work in the most economical manner. Other builders with less facilities should therefore be liberal in their estimates. Some contractors when estimating use a cost unit for reinforced concrete of $1 per cu. ft., or $27 per cu. yd., for all material in place, which is no doubt large enough for even inexperienced builders.

Where wooden buildings are referred to in the following comparisons, only mill construction of the slow-burning type is considered, for nearly all modern industrial enterprises are housed in buildings that are to some extent fireproof. The question may reasonably be asked here, what constitutes a fireproof building? Nothing is more fireproof than a furnace, and yet the decomposition of its contents by fire is its chief use. These buildings must therefore not only be made of non-inflammable material but they must be so arranged that fire when started can be confined to one room or to the smallest possible space. With this object in view, they should be equipped with self-closing metal doors, and windows with wire glass or metal shutters. They should have automatic fire alarms, and above all an adequate sprinkler system. Steel framing must be enclosed and protected with some material such as brick, tile, terra cotta or concrete. Under these conditions, with insurance on the contents, a manufacturing enterprise is reasonably safe.

Building types arranged in order of their relative first cost are as follows:

A. Complete steel frame, fireproofed, with curtain walls and plank floor.

B. Interior steel frame, fireproofed, with solid brick walls and plank floor.

C. Complete steel frame fireproofed, with curtain walls and reinforced-concrete floors.

TABLE XII. COMPARATIVE COST OF WOOD MILL CONSTRUCTION AND REINFORCED-CONCRETE BUILDINGS. (Compiled by J. P. H. Perry.)

Kind and place.	Size.	Stories.	Load lb.	Cost of wood Bld.	Cost of concrete Bld.	Concrete % more or less than wood.	Bid or Est.
Factory, Detroit	....	3	300	$28,000	$28,500	1.5 more	Bid
Factory, Jersey City	60 by 140	5	200	52,000	56,000	7.1 more	Bid
Factory, Grand Rapids	....	..	...	85,300	86,000	1.3 more	Bid
Factory, Fall River	112 by 112	4	...	74,000	82,500	10.3 more	Bid
Factory, Manchester	45 by 100	5	...	52,000	72,000	27.7 more	Est.
Warehouse, Boston	20 by 155	9	...	212,500	196,000	6.3 less	Bid
Warehouse, Jersey City	38 by 94	6	200	39,000	43,000	9.3 more	Bid
Warehouse, Pittsburg	100 by 120	4	...	61,500	63,600	3.3 more	Bid
Warehouse, Nashua	100 by 200	8	...	117,000	131,000	10.7 more	Bid
Press Bldg., Cincinnati	....	..	...	......	......	4.0 more	Bid
Bakery, Cincinnati	60,000 s.f.	..	300	64,000	62,500	2.3 less	Bid
Shop, Cincinnati	....	..	...	16,000	19,100	16.2 more	Est.
Shop, New England	....	..	...	65,800	69,500	5.2 more	Est.

D. Interior steel frame fire-proofed, with solid brick walls and reinforced-concrete floors.

E. Entire reinforced-concrete building.

F. Part interior steel frame not fireproofed, with solid brick walls and wood mill floors.

G. Entire wood mill construction.

The first cost, however, is not always the governing consideration, for in these times of large enterprises, any reasonable investment is permissible which will result in ultimate economy, when the expense of maintenance, depreciation, interest and insurance is considered. The selection of a building type is, indeed, a choice of the most profitable investment.

In comparing the first cost of buildings in wood mill construction and in reinforced concrete, it will be found that their relative cost varies with the location, size of building, and the floor loads to be sustained. In the Southern States, or other regions where timber is abundant and cheap, wood construction will often cost 25 to 30% less than reinforced concrete, while in districts where wood is scarce, the two types may be nearly equal.

The comparison depends also on the size of the building, for large ones have often been found to cost about the same in either material, and small ones are sometimes more expensive by 30 to 40 or 50% in reinforced concrete than in wood. The required floor capacity also affects the comparison. Light loads with long spans are cheaper in wood mill construction than in reinforced concrete, the cost of the two types being nearly equal in large buildings with 200 lbs. imposed loads per square ft., and column spacing of 18 to 20 ft. With loads of 300 to 500 lbs. per sq. ft., concrete becomes the cheaper, and the saving increases rapidly with greater loads of 1,000 to 1,200 lbs. per sq. ft.

A concrete building designed by the writer and containing about 500,000 cu. ft. was found to cost 17% more than one in wood mill construction, and about the same as a building with complete interior fireproofed steel frame, solid walls, and wood floors. It was in Ohio.

As a general rule, therefore, it will be found that reinforced concrete in the Northern States costs about the same as wood for large buildings with heavy loads, worth $250,000 or more. Those worth $25,000 to $100,000 will usually cost 10 to 20% more in concrete than in wood, and small structures, especially for light loads, may be cheaper in wood by 30 to 40 or even 50%.

Table XII gives a miscellaneous lot of bids and estimates on manufacturing buildings, with comparative costs in wood mill construction and in reinforced concrete. It will be seen that the costs in most cases are from 1 to 27% higher in concrete than in wood.

Comparing now the *ultimate* cost of the two types. For convenience, a wooden building will be assumed at $100,000, and a concrete building 10 per cent. more, or $110,000, and the contents in each case will be assumed of equal value to the building. The yearly maintenance costs will be:

	Wood.		Reinforced concrete.	
Depreciation	at 1½%	$1,500	at ½%	$ 500
Insurance on building......	at 80 cts.	800	at 20 cts.	220
Insurance on contents......	at 110 cts.	1,100	at 80 cts.	880
Interest and taxes.........	at 7%	7,000		7,700
Oscillation, vibration	at 1%	1,000		0000
Total		$11,400		$9,300

The reinforced-concrete building costing $110 000 will then have a maintenance cost of $2,100 per year, or 2.1 per cent. less than the wooden one at $100,000, and this difference of $2,100 at 6%, is interest on $35,000. It will therefore be permissible to invest an additional $35,000 on a concrete building, to make the two types of equal ultimate cost. A concrete building costing $145,000, or 45 per cent. more, has therefore no greater ultimate cost than a wooden one at $100,000.

In comparing the cost of fireproofed-steel construction with reinforced-concrete, complete framing and exterior curtain walls being considered in both cases, it will be found that for imposed floor loads of 150 lbs. per sq. ft. or more, concrete will be cheaper than steel by 5 to 20%, depending on conditions. For light loads, the cost of the two types will be nearly equal, and in some cases with very light load and long spans, steel framing will be slightly cheaper. One-story buildings over large areas are best when framed in steel.

A comparison on a building costing about $50,000 for total floor loads of 200 lbs. per square foot, showed that one with fireproofed-steel framing and heavy wooden floor cost 12% more than one of reinforced concrete with granolithic floor surface. It appears, therefore, that factory buildings of reinforced concrete have the lowest cost of all fireproof construction yet available.

Table XIII gives the comparative cost of a variety of buildings of different kinds, in both reinforced concrete and in steel. It shows that the former type is cheaper than the latter by 3 to 13%.

From comparative estimates for a building of 500,000 cu. ft., to determine the comparative cost of fireproofed-steel construction and wood mill framing, it appears that one with complete fireproofed-steel frame, side curtain walls and wood floors, costs 30% more than wood mill construction, while the same building with only interior fireproofed-steel frame and solid bearing walls costs 19% more than wood. If the first building mentioned above had a reinforced-concrete floor, its cost would be 37% more than wood mill construction, while the corresponding cost of the second one with reinforced concrete floor would be 26% more.

Cost of Reproducing Buildings and Yearly Cost Variation. The table in Fig. 7 shows the per cent. of increased cost to be applied to cost of buildings as of year built to obtain cost of reproduction in a recent appraisal by the authors.

Comparative Cost of Slow Burning and Concrete Buildings in Chicago. F. E. Davidson and T. L. Condron (Engineering News, Nov. 9, 1916), give the following comparison of work in Chicago:

TABLE XIII. COMPARATIVE COST OF BUILDINGS IN REINFORCED CONCRETE AND IN STEEL

Kind.	Place.	Size, ft.	Stories.	Load, lb.	Cost of reinforced concrete.	Cost of steel.	Concrete more or less than steel, per cent.	Bid or est.
Factory	Des Moines	66 by 132	6	200	$60,650	$69,750	13.0 less	est.
Factory	Fairmount	50 by 100	3	200	25,000	28,000	10.7 less	bid
Warehouse	Brooklyn	140 by 190	10	200	250,000	280,000	10.7 less	bid
Office	St. Louis	86 by 120	8	70	170,000	184,000	7.6 less	bid
Office	Cincinnati	....	17	70	......	......	4.0 less	bid
Mill	Boston	....	3	...	278,200	286,400	2.8 less	bid
	Cambridge	60 by 320	5	...	90,000	87,300	3.3 more	bid
Store	Indianapolis	71 by 120	6	125	89,500	96,000	6.8 less	bid
Hospital	Indianapolis	....	6	...	793,000	823,000	3.6 less	bid
Hotel	St. Louis	120 by 140	8	70	171,000	184,000	7.0 less	bid
Hotel	St. Louis	....	11	70	290,000	304,000	4.6 less	bid
Factory	Ohio	....	12	200	40,000	less than steel		bid
Loft	Springfield	105 by 283	9	150	280,000	320,000	12.5 less	bid

The Olson building is 55 ft. 1½ ins. by 124 ft. 7½ ins. in area, with six stories and basement, and contains 598,477 cu. ft. The story heights are in general 13 ft. 6 ins. floor to floor. The typical bays of the building are 18 ft. by 17 ft. 10 ins. The structure was designed for a live-load of 150 lbs. per sq. ft. in accordance with the requirements of the Chicago building code, which limits the stresses in long-leaf Southern pine to 1,300 lbs. per sq. in. in bending and 1,100 lbs. per sq. in. in direct compression with the grain.

The floor girders are composed of two 10 x 18-in. timbers bolted together, and the floor joists or beams are 8 x 16 in., located 4 ft. 6 ins. c. to c. The girders are carried on steel post caps of the writer's own design. The floor construction is a 3-in. tongued and grooved flooring finished with a ⅞-in. maple wearing surface.

This building is an addition to an existing factory, and it was necessary to use cantilever foundations for the entire structure. This, of course, is true for either design.

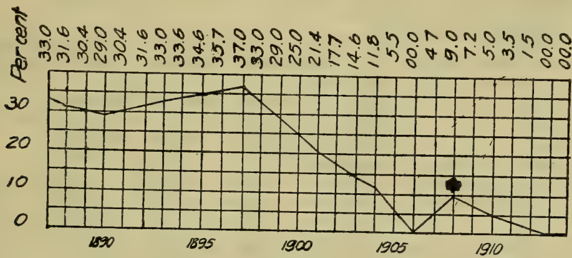


Fig. 7. Diagram showing per cent. of increased cost to be applied to cost of building as of year built to obtain reproduction cost in 1915.

The timber specified in the contract was to be of the select structural grade as per the new grading rules of the Southern Pine Association. The cost to the contractor in this particular building at the site was as follows: Approximately $34.50 per M. for the 18-in. stock and $33 per M. for the 16-in. stock.

The Imperial Brass Co. building is 85 x 125 ft. in area, six stories and basement, and has 74,000 sq. ft. of floor surface. The cubical contents measured in the same manner as adopted for the Olson building are 972,000 cu. ft. for the standard mill construction and 993,400 cu. ft. for the reinforced-concrete construction, the difference in cubical contents being due to the greater depth of foundations for the concrete construction. The typical bays of the standard mill construction are 18 ft. by 16 ft. 6 ins. and for the reinforced-concrete construction 18 ft. by 21 ft. 6 ins. The structures were designed for a live-load of 175 lbs. per sq. ft. in accordance with the requirements of the Chicago building code.

In the standard mill construction the floor girders are composed of two 8 x 18-in. timbers, bolted together, and the floor joists or beams are 8 x 16 ins. spaced 4 ft. 6 ins. c. to c. The girders are

carried on steel post caps built up of plates and angles. The floor construction is 3 in. tongued and grooved yellow-pine flooring with ⅞-in. maple wearing surface. The timber specified was select structural-grade Southern pine, according to the specifications for dense Southern pine given in the Southern Pine Association Density Rule Book of March 15, 1916 No. 1 Douglas fir was permitted as an alternate for the above yellow pine.

The reinforced-concrete design called for an 8-in. reinforced-concrete slab supported by flaring column heads, and reinforced-concrete round columns.

The foundations for the mill-construction building are the usual spread type, except that cantilever foundations are required on the side adjacent to the old building.

TABLE XIV. COMPARISON OF COSTS OF MILL AND CONCRETE CONSTRUCTION

Comparison of bids for a factory building of standard mill and reinforced concrete.	Olson bldg.		Imperial bldg.	
Type of construction	Mill.	Concrete.	Mill.	Concrete
Masonry (brick, stone and concrete)	$20,256	$56,766	$31,097	$80,000
Ornamental and miscellaneous iron, etc.	11,989	4,839	13,250	
Carpentry	14,374	.....	23,500	.....
Steel sash, glazing, painting, roofing, etc.	3,804	4,479	6,069	6,883
Plumbing (drainage)	615	725	1,536	1,669
Wiring *	1,100	1,250	1,830	2,060
Total bids received	$52,138	$68,059	$77,282	$90,479
Per sq. ft. of floor areas	$1.17	$1.51	$1.04	$1.22
Relative costs per sq. ft.	100%	129%	89%	104%
Relative costs per sq. ft.	.....	.....	100%	117%
Adding 28 cts. per sq. ft. of floor area to cover cost of sprinkler, heating and elevator equipment and plumbing fixtures	$1.45	$1.79	$1.32	$1.50
Relative costs per sq. ft.	100%	124%	91%	103%
Relative costs per sq. ft.	.....	.....	100%	114%
Per cu. ft. of building	8½c.	11¼c.	8c.	9⅛c.
Relative costs per cu. ft.	100%	132%	94%	107%
Relative costs per cu. ft.	.....	.....	100%	114%
Adding 2 cts. per cu. ft. of building to cover cost of sprinkler, heating and elevator equipment and plumbing fixtures	10½c.	13¼c.	10c.	11⅛c.
Relative costs per cu. ft.	100%	126%	95%	106%
Relative costs per cu. ft.	.....	.....	100%	112½%

The column spacing was modified in making up the mill design, changing the spans from 21 ft. 0 in. (concrete design) to 17 ft. 10 in. (mill design).

Brick per Square Foot of Floor and Approximate Costs of Mill Buildings. C. F. Dingman (Engineering and Contracting, Sept. 8, 1915), states that the size and shape of buildings should be taken into account when estimating costs on a square foot basis. For

* Estimates of wiring only.

example, a 25 by 25-ft. building will require more brick per square foot of floor area than a building 100 by 100 ft. The former would require 100 lin. ft. of wall to enclose an area of 625 sq. ft., or 1 lin. ft. of wall for each 6¼ sq. ft.. of floor area; while the latter would require only 400 lin. ft. of wall to enclose an area of 10,000 sq. ft., or 1 lin. ft. of wall for each 25 sq. ft. of floor. The same condition applies to footings, copings, wall flashings, etc. Such items as floor construction and roofing are almost directly proportional to the floor area, but the items included in the wall construction affect the total cost to such an extent as to make it unwise to attempt to give an approximate estimate of the cost per square foot without carefully considering the effect of size and shape.

To show the effect of changes in size and shape on the number of bricks required per square foot of structure, the data following are taken from estimates on actual buildings.

NUMBER OF BRICKS PER SQ. FT. OF FLOOR

Height, stories.	Size of building, ft.	Number of bricks per sq. ft. of floor.
1	32 x 85	35
1	35 x 89	25.4
1	36 x 100	23.2
1	50 x 106	17.7
1	67 x 97	15.4
1	69 x 92	8.3
1	53 x 181	8.8
1	75 x 120	16.5
1	80 x 100	8.7
1	82 x 253	6.6
1	60 x 218	12
1	140 x 180	6.3
2	42 x 82	14.1
2	94 x 126	6.7
3	40 x 146	10.6
3	50 x 96	13.4
4	50 x 100	16.2
4	111 x 201	9.4
5	72 x 102	10.9
5	72 x 157	17.5

The buildings are of the ordinary standard mill building type, that class being selected because it is in mill construction that we find the greatest uniformity and standardization of design; the values can therefore be considered fairly representative.

It is evident from the above that if a sufficient number of observations was made a series of curves could be prepared which would show approximately the number of bricks which would be required to construct a standard mill building of any size. It is evident, also, that these curves would show a diminishing quantity per square foot as the size of the building increased so long as its shape or plan remained square, but that it requires a greater quantity of material to enclose the same area in an oblong building than in a square building, and that this quantity increases as the ratio between the length and width increases.

The costs in Table XV may be taken as a guide by an engineer

or architect who desires to determine the approximate cost of a projected mill building having brick walls and located in the vicinity of — but not within — New York City. The costs are based on buildings in which the story heights are not over 12 ft. In New York City the costs may run from 5 to 10 per cent. higher, on account of the high cost of transporting materials, etc.

TABLE XV. COST OF ORDINARY BRICK MILL BUILDINGS

Size, ft.	1-story.	2-story.	3-story.	4-story.
25 x 25	$ 1,250	$ 2,500	$ 3,750	$ 5,000
50	2,400	4,800	7,200	9,600
75	3,440	6,700	9,600	13,100
100	4,200	8,100	11,850	16,200
50 x 50	3,800	7,500	11,200	13,800
75	5,100	9,750	14,100	18,750
100	6,450	12,100	17,400	23,600
125	7,750	14,500	20,600	27,000
150	9,175	16,950	24,100	31,800
75 x 75	7,050	11,900	19,500	25,600
100	8,925	16,200	23,900	31,800
125	10,680	20,250	28,125	37,500
150	12,500	23,000	32,700	43,600
100 x 100	11,400	21,600	28,200	37,200
125	13,500	24,500	33,200	44,000
150	15,900	28,500	38,700	51,000

Unit Costs of Reinforced Concrete for Industrial Buildings. C. S. Allen of Lockwood, Greene and Company, mill architects, in Engineering Record, April 6, 1912, says that concrete is especially adapted to heavy construction, and for heavy loads of 200 lbs. per sq. ft. and over, where the spans are 18 to 20 ft. Table XVI gives the unit costs, on both the square-foot and the cubic-foot basis, together with a general description of a number of reinforced concrete industrial buildings of different types. The average cost per sq. ft. of these buildings, excluding the one-story structures, was $1.12, while the average cost per cu. ft. was 8.7 cts. The one-story structures had reinforced concrete saw-tooth roofs and the average cost per sq. ft. was $1.77, while 8.5 cts. was the average cost per cu. ft. These costs are for the finished buildings, including plumbing, but do not include heating, lighting, elevators, sprinklers and power equipment. The cost per sq. ft. of floor area was obtained by dividing the cost of the building by the total number of sq. ft. of floor area exclusive of roof area, but including basement floors, and the cost per cubic foot by dividing the cubical contents into the cost of the structure.

While no coal pockets are included in the table, it has been the experience of this company that above 3,000 tons' capacity, reinforced concrete elevator coal pockets cost from $5.50 to $7.50 per ton of capacity. Standpipes, exclusive of the foundations, average from 2½ to 3 cts. per gal. of capacity.

The average unit cost of the 1:2:4 concrete in the floors, including the beams, girders and slabs, was $6.10 per cu. yd. and for the columns $6.70 per cu. yd. Where a 1:1½:3 mixture was used for the columns, the average cost was $7.60 per cu. yd. This cost was made up of the items of cement, sand, stone or gravel, labor and

TABLE XVI. UNIT COSTS OF REINFORCED CONCRETE BUILDING FOR INDUSTRIAL PURPOSES ERECTED 1911–12

Type.	Dimensions, feet.	Stories.	Story height, ft.	Live load, lb. per sq. ft.	Construction type.	Column spacing, ft.	Total cost per sq. ft.	Total cost per cu. ft.
Machine shop..	120 x 50	4	12.0	150	Beam	10.0 x 24.0	$1.17	$0.09
Cotton mill....	550 x 129	2	16.0	75	Beam	10.8 x 25.0	0.98	0.07
		4	12.6	150	Flat slab	17.0 x 20.0	1.09	0.077
Weaving mill..	140 x 60	5	12.6	150	Flat slab	17.6 x 20.0	1.50	0.12
Knitting mill..	220 x 75	2	14.0	125	Beam and girder...	22.0 x 25.0	1.09	0.073
Factory	223 x 56	2	16.0	300 & 1,000	Beam and girder...	18.6 x 18.6	1.55	0.10
Weave shed ...	341 x 231	1		125	Sawtooth skylight..	13.0 x 21.4	1.79	0.07
Machine shop..	220 x 100	1		125	Sawtooth skylight..	20.0 x 20.0	1.75	0.10
Storehouse	181 x 56	4	14.6	150	Flat slab	18.0 x 20.0	1.15	0.07
Storehouse	580 x 109	10	12.0	250	Beam and girder...	19.3 x {19.0, 25.0}	0.85	0.071
Storehouse	....	..	...	...	....	....	0.76	0.05
Storehouse	256 x 100	12	8.0	150	Flat slab	16.0 x 16.8	1.04	0.12

plant. The cement, of course, varied greatly with the demand, but the average net cost was $1.35 per barrel, including 3 cts. for tests. The sand averaged 80 cts. per cubic yard and the crushed stone $1.25 per cu. yd. The cost of labor of unloading the materials and mixing and placing the concrete varied from 65 cts. to $2.90 per cu. yd. The cost of plant, consisting of freight, depreciation or rental of mixing and hoisting towers, their erection, power and coal, and losses and waste on the small tools, ranged from 50 cts. to $1.50 per cubic yard of concrete placed.

On the average job the cost of the forms amounts to about one-third the cost of the entire structure. On the buildings under consideration, the average cost of the forms for the floors, including beams, girders and slabs, was 10 cts. per sq. ft. and for the columns 13 cts. per sq. ft. The lowest cost was in a building of flat slab type construction where, by the intelligent use of corrugated iron for the slab forms, the cost of the floor forms, including wall beams, was 7 cts. per sq. ft., and the highest cost was for an artistic but not elaborate overhanging on a 12-story building, which was 32 cts. per sq. ft.

The cost of the labor of making, erecting and stripping the forms varied, according to the price of lumber, design of the structure, method of forming, character of the supervision and the skill of the workmen, from 4¾ to 12 cts. per sq. ft. The cost of lumber, nails and oil divided by the square foot of forms averaged from 2¼ to 4½ cts. per sq. ft.

The cost of bending and placing the reinforcing steel, including the necessary wire, averaged $10 per ton, the range being from $5.75 per ton to $17.20 per ton.

Granolithic floor finish 1¼ in. thick, when laid before the concrete below it had set, so as to form one homogeneous slab, cost on the average 4½ cts. per sq. ft. When put on after the rough concrete slab the cost averaged 7 cts. per sq. ft.

The most common type of curtain wall under windows has been either an 8 or 12-in. brick wall resting on the concrete wall beam. The average cost of these walls has been 45 cents per square foot. There is practically no difference in cost between the 8-in. and the 12-in. brick curtain wall, as the saving in material is offset by the great amount of extra labor in culling and laying the thinner wall.

An excellent and inexpensive spandrel wall, according to Mr. Allen, is constructed by using 8 x 12 x 18-in. vitrified tile. This is a non-absorbent wall and when properly laid in cement mortar makes a tight weatherproof curtain wall. The cost averages about 25 cts. per sq. ft. If the tile is plastered both sides the cost is about 38 cts. per sq. ft.

Where 8-in. concrete curtain walls were cast in place after the skeleton frame was completed, the average cost was 40 cts. per sq. ft., and when poured simultaneously with the columns 48 cts. per sq. ft. Four-inch cast concrete slabs cost about 35 cts. per sq. ft.

While concrete blocks make a very cheap and light curtain wall, the price being about the same as for the 8-in. tile, Mr. Allen's ex-

perience with them has been rather unfortunate on account of their extreme porosity.

Where the location of the buildings has demanded special treatment of the exposed surfaces, this company has generally specified rubbing with a block of carborundum. The average cost of this work has been 4 cts. per sq. ft. In two instances portions of the structure have been bush-hammered, with a resulting average cost of 7 cts. per sq. ft.

Concrete piles were used on the foundation of several of the buildngs and the average cost of the piles was $1.15 per lin. ft.

Where, for waterproofing purposes, hydrated lime has been added in the proportion of 10% of the weight of the cement, the added cost per cubic yard of 1:2:4 concrete has been 50 cts. Patented compounds have cost from 25 to 35 cts. per square foot of surface covered. On horizontal or inclined surfaces the company has sometimes used a granolithic surface of rich mortar of Portland cement and sand, or Portland cement and screenings in the proportions of 1:1 laid at the same time as the base and troweled as in side walls construction. The cost of this work has been about 5 cts. per sq. ft.

Taken as a whole, the lowest possible cost on a reinforced concrete building can be obtained, according to Mr. Allen, only by a careful study of each particular case to determine the cheapest type of construction and most economical spacing of columns. As a general proposition, for light loads with ordinary beam and girder construction the most economical spacing of columns has been 18 ft. each way and for flat slab construction 20 ft. each way. For heavy loads, such as 300 lbs. per sq. ft. and over, the cheapest column spacing for beam and girder construction is 15 x 15 ft. and for flat slab construction 17 x 17 ft.

Cost Chart for a Reinforced-Concrete Factory Building. An analysis of the distribution of the various elements of cost in a modern four-story reinforced-concrete machine shop at Lowell, Mass., appears in the accompanying diagram. It was prepared by the Aberthaw Construction Company, of Boston, and is said to represent a fairly typical case, both as regards distribution and as regards the character of the building itself.

The building is 150 x 50 ft., with brick curtain walls. The general type of interior construction is beam and girder, the height between finished floors being 12 ft. 4 ins. The two lower floors were designed for live loads of 250 lbs. per sq. ft. and the upper floors for 150-lb. loads. Floorbeams are carried on a single row of columns 10 ft. on centers, running the length of the building midway between side walls. Steel sash was used throughout.

Cost of Two Story Reinforced Concrete Factory. D. L. C. Raymond (Engineering and Contracting, Apr. 29, 1908), gives the following relative to a building erected in 1907 at Walkerville, Ontario. It is a two story factory, 100 x 100 ft., with 18 ft. clearance on the first floor and 12 ft. on the second. It is skeleton type of construction, 16 x 16 ft. floor panels, and 6-in. curtain walls. Steel rods were used for reinforcement with wire mesh in the slabs. A 1:2:4 mixture was used, the mortar finish on the floors being 1:2.

The columns and beam forms were 2-in. dressed pine, supported by 4 x 4 stuff. The floor forms were 1 in. laid on 2 x 4 pieces spaced 18 ins.

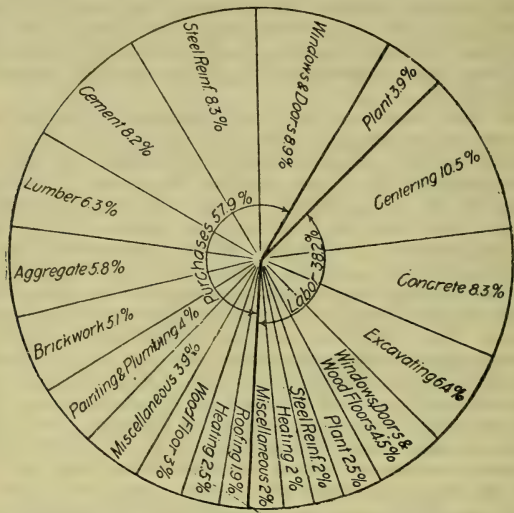


Fig. 8. Cost chart for concrete building.

The men were all green at the work. There were 847 cu. yds. of concrete, the cost of which was as follows:

	Total.	Per cu. yd.
Materials:		
Cement at $2.05 per bbl.	$ 3,314	$ 3.91
Sand and gravel at $1.25 per cu. yd.	1,054	1.25
Reinforcement at $55 per ton	2,314	2.73
Lumber for forms at $27 per M	4,944	5.84
Nails	107	0.13
Total materials	$11,733	$13.86
Labor:		
Building runs, mixing and hoisting concrete	$ 872	$ 1.03
Placing and tamping concrete	562	0.66
Placing reinforcement	221	0.26
Stripping and cleaning forms, etc.	380	0.45
Carpenters building and setting forms	2,010	2.38
Superintendence	714	0.84
Tools and depreciation of plant	338	0.40
Total labor	$ 5,097	$ 6.02
Grand total	16,830	19.88

It will be noted that no salvage is allowed for the lumber, and that 216 ft. B. M. were used per cu. yd. of concrete. The carpenter

work on the lumber cost $11 per M. The cost of stripping lumber and cleaning up amounted to a little more than $2 per M.

There were 100 lbs. of reinforcement per cu. yd., and the labor of placing it was only a trifle more than ¼ ct. per lb.

This building contained about 320,000 cu. ft. of space. Hence the cost of the concrete alone was 5¼ cts. per cu. ft., which is a low cost. The cost per square foot of floor area (2 stories) was 84 cts., not including windows, etc.

Unit Costs of Forms and Concrete in Building Construction. L. C. Wason of the Aberthaw Construction Co. in Engineering Record, Jan. 16, 1909, gives the following costs of concrete buildings taken from data collected by his company.

By reference to the general averages on form work, Table XVII, in the tables of forms per square foot of surface contact, namely, columns, $0.13; floors with reinforced concrete beams, $0.116; flat floors without beams, $0.111; short span slabs between steel beams, including the fireproofing on the sides of the beams, $0.095; walls exposed to view above ground, $0.128; foundation walls, $0.103; mass foundations, $0.093, these figures will be found to be all higher than usually believed to be a fair cost by the majority of builders. It is upon the success of handling forms that good results financially depend.

In regard to concrete, labor is the variable item which must be carefully considered. Any one of intelligence can make a careful estimate of the materials to be used, but note the average prices per cubic foot of labor, namely, for columns, $0.123; beam floors, $0.131; flat floors, $0.106; floors between steel beams, $0.121; walls, $0.106; foundations, $0.091, and mass work in connection with building,

TABLE XVII. UNIT COSTS OF CONCRETE BUILDINGS

	Forms per sq. ft.				Concrete per cubic foot						
Concrete Columns.	Carpenter labor.	Lumber.	Nails and wire	Total.	Concrete labor.	General labor.	Cement.	Aggregate.	Team and miscel.	Plant.	Total.
Highest	.133	.082	.002	.181	.166	.056	.109	.084	.041	.034	.340
Lowest	.057	.013	.001	075	.064	.003	.062	.027	.008	.013	.271
Average of 9	.082	.036	.001	.130	.096	.027	.085	.049	.021	.023	.301
Beam Floors of Reinforced Concrete.											
Highest	.165	.107	.004	.275	.186	.035	.194	.101	.052	.055	.470
Lowest	.037	.027	.001	.067	.047	.004	.071	.037	.007	.010	.202
Average of 18	.070	.045	.002	.116	.111	.020	.106	.063	.025	.024	.354
Flat Slab Floors.											
Highest	.078	.039	.003	.118	.146	.017	.109	.084	.026	.039	.374
Lowest	.067	.037	.001	.106	.043	.004	.087	.053	.012	.010	.252
Average	.071	.038	.002	.111	.097	.009	.096	.070	.019	.024	.315
Concrete Slabs between Steel Beams.											
Highest	.110	.071	.003	.184	.144	.048	.208	.080	.064	.046	.428
Lowest	.028	.012	.001	.049	.073	.005	.076	.026	.004	.010	.272
Average	.061	.032	.002	.095	.102	.019	.128	.068	.024	.017	.359

	Forms per sq. ft.				Concrete per cubic foot						
Building Walls above Grade.	Carpenter labor.	Lumber.	Nails and wire	Total.	Concrete labor.	General labor.	Cement.	Aggregate.	Team and miscel.	Plant.	Total.
Highest	.136	.073	.005	.176	.146	.052	.105	.187	.077	.055	.446
Lowest	.046	.016	.001	.079	.042	.004	.034	.043	.007	.005	.174
Average of 17.	.085	.036	.002	.128	.090	.016	.073	.076	.025	.019	.301
Foundation Walls.											
Highest	.134	.048	.004	.193	.213	.037	.203	.116	.057	.040	.599
Lowest	.032	.009	.001	.056	.040	.002	.038	.027	.003	.010	.148
Average	.068	.033	.002	.103	.076	.015	.080	.062	.019	.017	.269
Footing and Mass Foundations.											
Highest	.119	.077	.003	.198	.081	.020	.098	.099	.013	.049	.275
Lowest	.016	.006	.001	.018	.025	.001	.047	.043	.003	.010	.181
Average of 10.	.057	.034	.002	.093	.045	.007	.071	.077	.007	.021	.229

Steel.	Cost per ton.
Highest	$16.47
Lowest	2.54
Average of 21	8.52

$0.052; not until the last item is reached is a price obtained in experience which the majority expect to obtain in building work in general.

The table of steel omits entirely the first cost of the material. After it is received at the site of the work in the shape sold by the manufacturer, these prices cover the cost of fabricating into units for columns or beams, bending the stirrups, placing and all incidentals whatsoever prior to the actual embedding in concrete.

Unit Cost of Concrete in Buildings. The unit costs of concrete in the buildings of a light and power plant in California, including the cost of delivering material with a wagon haul not exceeding one mile, were as follows:

Foundations, not reinforced, using 1:3:6 concrete,

	Cost per cu. yd.
Material	$5.79
Labor	2.25
Total cost of foundations..............	$8.04

Floors, not reinforced, using 1:2½:5 concrete,

	Cost per cu. yd.
Material	$6.30
Labor	2.75
Cost of plain floors..................	$9.05

Reinforced floors, using 1:2:4 concrete,

	Cost per cu. yd.
Material	$6.30
Labor	3.25
Cost of reinforced floors..............	$9.55

Walls and Roofs, reinforced, using 1:2:4 concrete,

	Cost per cu. yd.
Material	$7.06
Labor	4.00
Cost of walls and roofs	$11.06

Forms, for Roofs, Walls and Floors,

	Cost per sq. ft.
Material	$0.04
Labor	.07
Cost of roof, walls and floor forms	$0.11

Forms for Foundations,

	Cost per sq. ft.
Material	$0.05
Labor	.02
Cost of foundation forms	$0.07

Surfacing Floors, 1½ in. thick, using 1:1½ mortar,

	Cost per sq. ft.
Material	$0.05
Labor	.02
Cost of surfacing floors	$0.07

Plastering Concrete Walls, mortar ½ in. thick,

	Cost per sq. ft.
Material	$0.015
Labor	.020
Cost of plastering concrete walls	$0.035

Cost of a Concrete Storage Warehouse Using Precast Members. W. H. Mason (Engineering News, Feb. 20, 1908), gives the cost of a cement storage warehouse 144 by 360 ft. in plan and 30 ft. high, having a capacity of 350,000 bbls. of cement. The side walls are 2 ft. thick at the top and 7 ft. thick at the ground, being designed as retaining walls. The building is one story high, the roof being 12 by 6 ft. by 4 in. precast slabs carried on girders resting on 32 ft. columns.

The roof slabs, girders and columns were cast in a shop about ½ mile from the warehouse and were completed in 2 months. Some preliminary work had been done previously, such as setting up concrete mixer, laying railroad track, and making a few casting floors to start on. The average number of men employed during this time was 23. Eleven of these were classed as carpenters and foremen, whose average rate was 24 cts. per hour; twelve were classed as laborers, whose average rate was 15 cts. per hour.

The lumber used for making the 1,048 pieces was 7,000 bd. ft., which at $27 per M. makes a total of $189.

The total amount of steel used was 201,400 lbs., the average price of which delivered at our mill was .0203 cts., or a total cost of $4,088.

The mixture used was 1 to 6, using the run of crusher stone without sand. The stone would all pass a ¾-in. screen.

In the following costs the stone is figured at 60 cts. per cu. yd., while the cement is figured at $1.00 per bbl.

Cost of each column complete on casting floor was as follows:

Cost of steel	$ 7.57
Cost of material for concrete	5.48
Carpenter labor	4.27
Labor, making and placing concrete and reinforcing	1.95
Total per column	$19.27

The columns are 18 x 18 ins. sq. and 32 ft. long with offsets at the base which bring their contents up to 2.8 cu. yds.

Cost of each girder complete on casting floor was as follows:

Steel	$ 5.53
Concrete material	3.51
Carpenter labor	2.26
Labor, mixing and placing, etc	1.34
Total per girder	$12.64

The girders are 12 x 26 ins. x 24 ft. with a contents of 1.9 cu. yds.

Cost of each roof slab complete on casting floor was as follows:

Steel	$1.69
Concrete material	1.85
Carpenter labor	.423
Labor, mixing and placing concrete, whitewashing, smoothing tops, etc	.405
Total per slab	$4.37

There are 72 sq. ft. in each slab, therefore the cost per sq. ft. is 0.0607 cts., or $6.07 per 100 sq. ft.

The estimated cost of erecting 518 squares in the building was as follows:

Cost of erection per square is	$1.86
Cost of slabs per square	6.07
Total cost in place	$7.93

One of the roof slabs tested to destruction failed at 7,700 lbs. center load, with 12-ft. span. This gives an ample factor of safety for a roof.

Cost of a Brick and Steel Factory in Pennsylvania. A. E. Duckham (Engineering and Contracting, Apr. 15, 1908) gives the cost of a building for a wireglass plant in South Greensburg, Pa., 60 by 170 ft., that was started on May 20, 1907, and was finished on Aug. 1. This includes the lehr (furnace) foundations.

The foundations up to the level of the ground are of concrete, made of 1 part cement (Portland), 3 parts sand, and 7 parts gravel. They were carried down to clay, which on an average was 3 ft. below the surface of the ground — which was level. The ground being marsh-like, the trenches were dug and immediately filled up

with concrete, mixed on the board and deposited by wheelbarrow from a plank runway into the bottom; no water was required in the mixing-board for the bottom layers of concrete owing to the trenches being partly filled with surface water.

Above the level of the ground the building is of brick. The roof-trusses are of steel, including the purlins. They rest on the pilasters of the wall, and are attached to them by anchor bolts. The latter were set loose in the walls; and, after the erection of the steel, were grouted with cement mortar. This was to facilitate the erection of the steel-work.

The roof was covered as follows: Nailing strips of 2 x 4 in. hemlock were bolted (every 3 ft.) to the steel purlins, and upon them was nailed 1⅝ in. matched yellow-pine sheathing; upon this was laid and fastened magnesia flexible cement roofing.

The building was well situated for receiving materials, as it was located 118 ft. from the railroad and 75 ft. from a street. The cement, sand, gravel and brick were obtained from local dealers within a mile of the place; the first three were hauled by wagon (with the exception of one carload of sand), and the last one was shipped in by car on a siding opposite the building, and slipped in by a chute — the railroad track being about 8 ft. above our ground.

The walls between the pilasters are only 9 ins., but the pilasters project 9 ins., thus making an 18-in. pillar or column under each truss to carry the load; the 9-in. wall between acting as a curtain wall. The brick wall was laid complete in cement mortar, no lime being used.

Four ordinary circular ventilators were used along the ridge. As there were many large windows along the sides of the building, as well as the ends, these were considered enough for the purpose. The windows had boxes for pulleys and weights. There were two sash to each window. The bottom sash weighed 39 lbs. including the glass: this was weighed to determine the size of counter-weights.

The 122 squares of roof-covering took one week to lay, nail, cement, and paint. There were five men for three days and two men for six days. Two men (experts) came up on the job, and three ordinary local mechanics were hired. The extra men cost $20.

In unloading the brick from the cars on the railroad track, in one case it took five hours to unload one box car of 12,000 brick with four men (two inside and two outside), with chute; and in another it took 3¾ hours for five men to unload the same car.

The detailed cost of the building as built was as follows:

Steel-work	$2,730.00
Lumber, doors and windows, sheathing, etc.	1,283.64
Roof covering (cement roofing felt)	412.50
Cement, sand and gravel	938.04
Brick	738.45
Labor (including common labor, bricklayers and carpenters)	2,175.58
Bolts to fasten nailing-strips to purlins	28.88
Hardware	79.54
Ventilators (circular)	18.00
Total	$8,404.63

The cost of the building per cu. ft. of space from the ground level to the roof was 3¼ cts. The cost per sq. ft. of floor space was 82.4 cts. The above does not include the architect's fee of 5% or the contractor's fee (of approximately 8%): this would bring the cost per cubic foot up to 3.6 cts., and the cost per square foot up to 93.1 cts.

The lehr walls (foundation) were built by the writer under a separate contract with the furnace contractors. This work he did for $6.50 a cu. yd. for the concrete walls (3 ft. under ground and 4 ft. above ground) and 50 cts. a cu. yd. extra for excavating the trenches. At this figure, he made 18% profit.

Cost of Buildings for Small Pumping Station. W. S. Johnson (Engineering and Contracting, Sept. 30, 1914) gives the cost of several small stations for municipally owned water works in Massachusetts as shown in Table XVIII.

TABLE XVIII. COST OF SMALL PUMPING STATIONS

Material.	Size.	Cost.	Cost per sq. ft.
Cobbles	22 x 30	$1,935	$2.93
Brick	19 x 36	1,857	2.71
Cobbles	9 x 12	350	3.24
Wood and steel shingles over entire surface	......	1,730	...
Brick	24 x 26	1,948	3.12
Brick	24 x 30	1,628	2.26
Brick	20 x 35*	2,500	3.57
Brick	30 x 40	2,368	1.97
Brick	24 x 34	3,100†	3.80†
Brick	......	....	...
Brick	33 x 23	2,000	2.64
Brick	24 x 24	2,000	3.46
Brick	28 x 28	2,852	2.68
Brick	25 x 36	2,700	3.00
Brick	25 x 36	2,133‡	2.37‡
Brick	16 x 16	500‡	1.95‡
Brick	25 x 36	1,647‡	1.83‡

* Two stories.
† Includes some grading.
‡ Without pumping machinery foundations.

Construction Camp Building Costs. C. A. Bryan (Engineering and Contracting, July 2, 1913), gives the first cost of a camp, including a well for water supply and other accessories as $10 per man accommodated. The dining and store building cost just under 30 cts. and the bunk house just over 30 cts. per sq. ft. of area.

Cost of Mill Erection. H. T. Curran (Engineering and Contracting, Oct. 6, 1915), states that erection costs are variable and can only be obtained by experience or by comparison with other jobs. However, if the following rules are applied for summer work in the United States, the estimate will come approximately close to actual cost. Labor wage is based on the average paid in western mining camps.

Superintendence can be figured when conditions are known, and will average, including cost of plans, from 3 to 5% of the total.

Excavation by picking, shoveling, and hauling average earth in wheelbarrows, moving 100 ft., will cost about 45 cts. per cu. yd.; add one-third of hourly wage of laborer for every additional 100 ft. Where mine cars can be used to advantage this may be cut to 35 cts. per cu. yd., moving 100 ft.; add one-fifth of hourly wage for every additional 100 ft., which covers placing the track. Breaking rock by hand, like hauling conditions, will cost from $1.25 to $1.75 per cu. yd., with 100 ft. haul. It will cost a few cents more per cubic yard than in earth work for every additional 100 ft. There are so many unknown quantities entering into excavating that these figures are only roughly approximate.

Rubble masonry will average $5 per cu. yd., using cement mortar. A mix of 1 part of Portland cement to 5 parts of sharp, clean sand will give good results. Such walls will average about 15-in. courses and will require from ¼ to ⅓ cu. yd. of mortar per cubic yard of wall.

Concrete work can be figured to a nicety when conditions are known. With a mechanical mixer, $1 per cu. yd. will cover the cost of mixing and placing in the average mill. On a large job it is well to determine just what mix is required with the material used. The duty of the sand is to fill the voids in the broken rock and, when the two are mixed, the resultant voids should be filled with cement. It is well to allow 10% excess in each case, but there is nothing gained by using a richer mix for retaining walls and foundation. However, if a weaker mix is desired it can be obtained by puddling instead of cutting down the proportion of sand and cement. In forms of any size puddling is good practice and the strength of the concrete is by no means decreased. Clean, firm rock should be used and the edges should not touch. On the average mill job concrete will not cost more than $7 per cu. yd. for large forms, $8 for medium, and $10 for small and heavy-duty machine foundations, including the cost of the forms. By using old iron, reinforced concrete can be made for 50 cts. per cu. yd. more. Floors with a 5-in. base and 1-in. covering will average from $10 to $14 per cu. yd.

Carpenter work with a well organized crew of millwrights will average about $21 per M for framing and erecting; $12 to $15 per M for siding and roofing; and $2.50 per M for shingles, or 75 cts. to $1 per square for corrugated iron roofing and siding. With a picked-up local crew, $28 to $31 per M for framing and erecting, $9 per M for siding and roofing and $2.50 per M for shingles or $1.25 per square for iron, will be the average figures.

The nails required in this work per M ft. b. m. will be about as follows:

NAILS REQUIRED IN ERECTION PER M. FT. B.M.

	Size, d.	Lbs.
Siding and roofing	8	18 to 21
Flooring (1-in. material)	8	28 to 32
Flooring (2-in. material)	20 or 30	20 to 25
Studding, etc.	10	14
Shingles (per 1,000)	4	6

Cost of Shop Drawings for Structural Steel. R. H. Gage (Engineering and Contracting, Aug. 28, 1907), gives the cost of preparing shop drawings in Chicago in 1906.

The structural shop in which the cost studies were made has a capacity of 800 tons per month. The drafting department employs on an average seven or eight engineers. All the work is standardized with regard to details to as great an extent as possible, in order to decrease the work in the drafting room, yet not to such an extent that it would be difficult for the shop men to read the drawings. For example, all beam, steel and cast-iron column connections, with the exception of special cases, are not drawn and dimensioned completely, but merely indicated. The shop and drafting room have been provided with a set of the firm's standards, which have all these connections drawn out completely with dimensions and which give lists of the material.

The data here presented were taken from a great variety of work, such as public and private school buildings, churches, breweries, malt houses and elevators, grain bins, warehouses, libraries, hospitals, apartment buildings, factories and manufacturing plants, train sheds, mill buildings, office buildings, electric lighting plants and pumping stations.

The following table shows the character of the buildings and also the average cost of preparing the drawings. The cost of drafting material and blue prints is not included. Where the material for the work is to be ordered from the mill and not taken from stock, the cutting bills or mill orders are taken as being part of the details.

COST OF SHOP DRAWINGS.

Character of building.	Avg. cost per ton.
Entire skeleton construction, i.e., loads all carried to the foundation by means of steel columns	$1.45
Interior portion supported on steel columns; exterior walls carry floor loads and their own weight	1.22
Interior portion carried on cast iron columns; exterior walls support floor loads as well as their own weight	.70
No columns and floor beams resting on masonry walls throughout	.85
Structure consisting mostly of roof trusses resting on columns	2.47
Structure consisting mostly of roof trusses resting on masonry walls	1.25
Mill buildings	2.56
Flat one-story shop or manufacturing buildings	.74
Tipples, mining structures or other complicated structures	4.88
Malt or grain bins and hoppers	2.47
Remodeling and additions where measurements are necessary before details can be made	1.87

Estimating Structural Steel. G. A. Merrill (Engineering and Contracting, Nov. 5, 1913), says the cost of the work is generally made up as follows: (1) The cost of the fabricated material F. O. B. cars point of delivery. (2) The cost of unloading and teaming to the building. (3) The cost of erection and field painting.

In taking off quantities from the plans, each beam, or each group of beams which are alike, is noted with the number of beams, size,

weight per foot, the kind of shop work to be performed, the number of end connections, recording by distinct abbreviations, whether such connections are to another beam or girder, or to a column, bearing plates and anchors if any. The usual classification for beams is as follows:

Plain. Cut the length with a variation of not over ⅜ in. from ordered length.

Single Punched. Punched one size hole in either web or flange.

Double Punched. Punched one size hole in both web and flange.

Framed. Having connection angles at one or both ends riveted or bolted to connect with some other member, and with one or both ends, if required by the framing, coped to engage the flange of a supporting beam or beams.

Bolted and Separated. Two or more beams made into a single member by the use of bolts and separators.

Riveted. Having plates, or angles, of shorter lengths, or running the entire length of the beam, riveted to the flange or flanges, or to the web of the beam.

Fittings. Connection angles, bolts and separators. In dealing with riveted beams, the estimator has the option of treating the beam together with the plates or angles riveted to it as a riveted beam, or to regard the beam alone as single punched, double punched or framed, and classify the plates, or angles, as fittings, choosing whichever method gives the cheaper cost.

Tie rods, bearing plates and anchors, are generally figured by themselves and not classified as fittings.

The length of beam is taken center to center of girders, or face to face of columns, and the steel estimator's sheet appears somewhat like this:

(1)	2,	15 x 42	D P 2C..........................	16–8
(2)	4,	12 x 315	F' 1C..........................	14–1
(3)	1,	12 x 40	S P 1a 1b 1c................	14–1
(4)	2,	8 x 18	B & S 2b.....................	12–0
(5)	1,	15 x 60	riv. 2C......................	18–2
	1,	12 x ⅜ pl		

Item (1) signifies two, 15-in. x 42-lb. beams, each 16-ft. 8-ins. long, double punched and connecting to columns at both ends.

Item (2), four, 12-in. x 31½-lb. beams, each 14-ft. 1-in. long, each having standard connection angles at one end, and connecting to a column at the other end.

Item (3), one, 12-in. x 40-lb. beam, 14-ft. 1-in. long, single punched, connecting to a column at one end, and with a bearing plate and anchor at the other.

Item (4), two, 8-in. x 18-lb. beams, bolted together and with bearing plates at both ends.

Item (5), a 15-in. x 60-lb. beam, 18-ft. 2-ins. long, with a 12-ft. x ⅜-in. plate riveted upon one flange, connected to columns at each end.

Connection angles are figured separately from the beams, the weight of a pair of standard connection angles with the rivets re-

quired being taken from the Carnegie or Cambria steel hand book.

In computing the weight of connection angles, the beam sheets are run over and all connections of the same weight are grouped together. With riveted beams, the weight of beam with all plates, angles and rivets, except connection angles, is taken together.

Often in a steel frame, the outside members consist of two channels, or an I-beam and channel, with an angle riveted to the channel. Such a member is generally split up and the I-beam or one of the channels is considered bolted and separated, while the remaining channel with its angle is considered as riveted.

The usual shop prices for beam work per 100 lbs. are as follows:

	Cts.
Cutting to length + ⅜-in.	00
Single punched	15
Double punched	25
Framed	35
Bolted and separated	35
Riveted	50

Beams over 15 ins. in depth cost 10 cts. per 100 lbs. extra.

In summarizing the weight of beams for shopwork, this is most easily taken care of by including the deeper beams in a classification one step ahead; thus, a single punched 18-in. beam would be included with double punched beams 15 ins. and under.

There is a further charge of, generally, 5 cts. per 100 lbs. for painting, and sometimes a charge of 5 cts. or 10 cts. per 100 lbs. for drawings. The steel contractor may be called upon by the specifications to pay a charge of 75 cts. to $1.25 per ton for inspection.

Fittings are generally figured at $1.55 per 100 lbs. for shopwork. Tie rods at the price of the rods and nuts plus freight, plus 50 cts. per 100 lbs. for shopwork. Bearing plates, allow about 15 cts. per 100 lbs. for cutting from the long plate. Anchors, generally a small item, figure at 3 lbs. each, and 4 cts. per pound.

Sometimes beams are framed into another beam on an angle or skew, at one or both ends. In this case, the beam is classified as framed, but the connections, which must be heated and bent, are classified as bent connections, and priced at a higher rate than ordinary fittings, say 6 cts. per pound for material and shopwork.

To the base price of the beams at the mill should be added the cost of shopwork, and these different costs multiplied by the tonnage of each sort of work.

The items of freight, paint, drawings and inspection are more easily figured from the total weights of steel.

In building work riveted work generally includes the following: (1) Columns, (2) Beam Girders, (3) Plate Girders, (4) Trusses.

Columns may be I-beams, Bethlehem H-sections, latticed channels, latticed angles, plates and angles, with or without flange plates, and plates and channels. The Z-bar, column, once a favorite, is now rarely used. In figuring the weight of columns, the size, weight per foot, and length of the principal members are taken off, and the weight of the column shafts computed. To the weight of the column shafts must be added:

(1) Weight of hitch angles at bottom, and steel base plate if one is used.

(2) Weight of splice plates.

(3) Weight of connections of beams to columns. The beam sheets are run over, and the number of connections noted and computed, keeping connections of the same weight together. The weights of such connections are given in some of the steel hand books. Often they may be computed from a typical column detail furnished with the framing plans.

(4) *Weight of rivets:* In plates and angles, and plates and channel columns, rivets will run from 6% to 5% of the weight of shafts with fittings, beings less with heavy shafts. With I-beams or Bethlehem H-sections, the rivets must be estimated with each plate or angle attached, calling each rivet (say) ½ lb.

In latticed angle columns allow 40% of the weight of main members. For lattice bars and rivets, and for latticed channels, 60 per cent.

Beam Girders. Take the weight of beams with cover plates and allow 2 lbs. to 3 lbs. per foot for rivets.

Plate Girders. If stiffeners and fillers are taken off, add 5% to 6% for rivets, according to whether the girder is light or heavy. If only the main members of the girder are taken off, add 15%.

Trusses. Take off the sizes and lengths, center to center, of joints and add 30% for light trusses made up of 2½ x 2-in. angles, and 25% for trusses having chords of 4 x 3-in. angles, or more.

For the small work included with the structural steel in building work, such as framing for pent houses, skylight curbs, bulkheads, cornice brackets, take the weight of the main members and add 25%. Price at 3 or 4 cts. per lb. for material and shopwork.

It is a general principle in estimating riveted work, that light work with considerable shopwork must be priced high, and as the work grows heavier, to decrease the pound price.

The prices for riveted work are not as definite as those for beam work. Fair average prices would be about as follows:

	Cents.
Beam girders, per 100 lbs.	60
Plate girders (according as the work is heavy or light)	55 to 80
Columns —	
I beam columns	50
Plate and angle	65 to 75
Plate and channel	70 to 80
Beth. H columns	55 to 65
Latticed Ls	80 to $1.00
Latticed channels	80 to $1.10
Trusses —	
Very light	$1.25
Ordinary	$1.00
Heavy	$0.85

Cast Bases: Usually columns rest upon cast bases. Sometimes the bases are detailed upon the framing plans, and in such cases the

weight can be readily computed, allowing 0.26 lb. per cubic inch. Often, however, merely the size of the bottom of the base is given, leaving the estimator to arrive at the weight as best he can. It is a good practice to record and preserve the weight of well proportioned cast bases, figured upon previous jobs, to use in cases such as these. The following are average weights for cast bases:

Ins.	Lbs.
24 x 24	525
27 x 27	675
30 x 30	850
33 x 33	1,050
36 x 36	1,275
39 x 39	1,500
42 x 42	1,750
48 x 48	2,300

The cost of cast bases varies from 2 to 2¼ cts. per pound.

To the cost of the fabricated material delivered upon cars must be added a profit. Just what profit to add depends upon conditions. If all the mills and structural shops are busy they will put on a higher percentage than in dull times.

The mills will generally quote on beam work at the prices previously given, without adding any profit.

The cost of teaming to the site can generally be figured close enough by estimating the weight of an average load, the number of trips per day a two-horse team will make, and the cost per day for such a team. If the pieces are heavy, the time of one or two helpers at the car must be added in.

The erection cost will vary with the character of the work, whether straight or crooked, light beams or heavy, whether the rivets are bunched together at column connections, or well scattered over the work, whether bolted or riveted connections.

A fair price is $10 per ton, although the figures may get down to $8 or up to $12. If unusually heavy girders or trusses occur in the work, it is best to figure the erection of these separately from the remainder of the steel.

Cost of Carpenter Work. C. A. Chalk (American Carpenter and Builder, March, 1914), gives the following labor cost of framing wooden houses with labor at 30 cts. per hour:

Floor space, including framing and setting joist, bridging and flooring of one thickness of 1 by 5-inch matched spruce or pine. Per 100 square feet, $3.00.

Partitions, including cutting and setting studding, trimming for door openings, furnished with pine base and quarter round — 17 cts. per foot run, measuring on the floor.

Outside walls, including strapping, finished with pine base and quarter round — 10 cts. per foot run.

Roofing, including rafters, sheathing cornice, shingling, ridge and wall — $6.50 per 100 square feet.

Outside doors, including setting frame in place for bricklayers, fit hinges, lock and case inside — $2.10 per door.

Inside doors, including nailing frame together and setting, casing two sides, fit hinges and lock — $2.40 per door.

Cased openings, including nailing frame together and setting, and casing two sides — $1.40 per opening.

Windows, box frame, sash weighted, including setting frame in place for bricklayers, fitting and weighting sash, cutting and nailing stops and casing — $2.40 per window.

Ceilings of collar ties fastened to rafters — $1.00 per 100 square feet.

Stairways, for straight stairs, strings worked on the job, set in place, wedged and glued, with starting newel and hand rail and landing newel, and, say, 12 feet of hand rail around well hole — the cost of labor will be about $1.00 per tread; where there are winders, add $1.50 for each window.

The above will apply to houses that cost from $1,800 to $2,200, all trim for paint finish.

E. W. Goode of Chicago, Ill., gives the following costs based on labor at 30 cts. per hour:

Making window frames, each	$ 1.25
Making door frames, each	1.00
Fitting inside doors, each	.75
Fitting outside doors, each	1.50
Putting up jambs, each	.15
Putting up casing, each	.20
Putting up lining, each	.15
Nailing base, per 100 lin. ft	2.40
Joists, per 1,000 ft. b.m	7.00
Studs, per 1,000 ft. b.m	10.00
Bridging, per 1,000 ft. b.m	6.00
Rafters, per 1,000 ft. b.m	10.00
Sheeting, per 1,000 ft. b.m	5.00
Rough floors, per 1,000 ft. b.m	3.20
Shiplap, per 1,000 ft. b.m	6.00
Siding:	
Plain 6-inch work, per 100 sq. ft	1.00
With long blank walls, per 100 sq. ft	.60
Mitered joints, per 100 sq. ft	1.70
Grounds and Furring:	
1 by 1-inch grounds, per 1,000 ft. b.m	25.00
1 by 2-inch grounds and furring, per 1,000 ft. b.m.	19.00
2 by 2-inch grounds and furring, per 1,000 ft. b.m.	15.00

Mortar Required and Cost of Brick Laying. Building Age gives the following data:

MORTAR REQUIRED TO LAY 1,000 BRICK.

Thickness of joint in inches	3/16	1/4	5/16	3/8	1/2	5/8	3/4
Mortar required per 1,000 brick, cu. ft.	8	10	12	15	18	22	26

COST OF MORTAR TO LAY 1,000 BRICK.

Lime Mortar: 1 part lime to 5 parts sand, with 3/8 to 1/2-in. joints.*

Quantity.	Rates.‡	Total cost per 1,000 brick laid.
3 bu.	$0.30 per bu.	$0.90
2/3 cu. yd.	1.50 per cu. yd.	1.00
		$1.90

Portland Cement Mortar: 1 part cement to 3½ parts sand, with 3/8 to 1/2-in. joints.†

Quantity.	Rate.‡	Total cost per 1,000 brick laid.
1¼ bbls.	$2.00 per. bbl.	$2.50
2/3 cu. yd.	1.50 per cu. yd.	1.00
		$3.50

* Slightly poorer than usually required. † Richer than usually required. ‡ Prices are only for comparative purposes.

Cost of Brickwork. The cost of brickwork as given by S. W. Emerson (Engineering and Contracting, April, 1906, p. 100), may be divided into two principal parts, cost of materials and cost of labor.

For common brickwork the cost of materials is a fairly constant quantity, but the labor cost varies greatly, depending on the class of work and rates of wages.

Units of Measurement. Brickwork in buildings is usually figured and paid for at so much per 1,000 wall measure. This is an arbitrary quantity and is a very different thing from kiln count or the actual number of brick. The rule usually adopted by engineers, is to figure 14 brick per sq. ft. of 9 in. wall; 21 brick per sq. ft. of 13½ in. wall, etc., deducting all openings. In other words 7 brick are allowed per square foot for each half brick thickness of wall. Figured this way a "thousand" brick represents 48 sq. ft. of 13½ in. wall or practically two cu. yds. and will be used in this sense throughout the present article. Masons frequently figure 22½ brick per sq. ft. of 13 in. wall, include all openings and figure corners twice.

Some arbitrary rule is necessary because of the variation in size of brick made by different manufacturers and in the thickness of the mortar joints.

An average size brick is 8¼ ins. to 8½ ins. long, 4 ins. wide and 2¼ ins. to 2⅜ ins. thick, although in some localities brick will be found measuring 9 ins. x 4¼ ins. x 2½ ins. and in New York City many are used as small as 7½ ins. x 3½ ins. x 2 ins. Brick 8½ ins. x 2¼ ins. with ⅜ in. to ½ in. joints will lay up about 900 brick per M.

Brick are bought by kiln count or the actual number and the price varies from $4.00 to $7.00 per M. at the yard.

Five to $6 per M. at the yard is a fair price to which must be added the freight or hauling.

The Amount of Mortar used depends on the thickness of the joints and the proportion of mortar in the wall will be about as follows:

⅜-in. joints	0.25
½-in. joints	0.33
⅝-in. joints	0.40

or as a "thousand" brick equals approximately two cu. yds., the cu. yds. of mortar required per M. will be:

⅜-in. joints	0.50
½-in. joints	0.67
⅝-in. joints	0.80

To make up a cu. yd. of 1 to 3 mortar requires about .85 cu. yd. of sand and 2 bbls. of lime or Portland cement. All cement mortar is seldom used except in engineering structures or underground work, while lime mortar is used only in the cheaper classes of work and should never be used in very heavy work or when exposed to dampness.

The usual practice is to use both lime and cement in the mortar, the relative proportions varying greatly according to circumstances.

One part lime and one part cement to six parts sand is a com-

mon specification but also one seldom lived up to. Figuring sand at \$0.50 per cu. yd., lime at \$0.50 per bbl. or \$0.20 per bu. and cement at \$1.75 per bbl. the materials for a cu. yd. of mortar would cost for 1 to 3 lime mortar:

.85 cu. yd. sand at \$0.50	\$ .43
2 bbls. lime at \$0.50	1.00
Total	\$1.43
.85 cu. yd. sand at \$0.50	\$ .43
1.0 bbl. lime at \$0.50	.50
1.0 bbl. cement at \$1.75	1.75
Total	\$2.68
.85 cu. yd. sand at \$0.50	\$ .43
2.0 bbls. cement at \$1.75	3.50
Total	\$3.93

One thousand brick, 8¼ ins. x 4 ins. x 2¼ ins., piled up solid without mortar, equals 1.65 cu. yds. If brick cost \$6.50 per M. the cost per cu. yd. would be \$3.96 or practically the same as cement mortar, but more than the mortar where part lime is used.

Cement mortar does not "work" easily, being hard for the bricklayers to spread. It is partly on this account that cement is so seldom used without adding at least a small portion of lime.

The cost of the sand may be practically nothing where it is dug out of the cellar and seldom runs as high as \$1 per cu. yd.

The labor cost may be divided into three classes, bricklayers, laborers and unloading materials.

An average first-class bricklayer should lay about as follows, in 9 hrs.:

In 9-in. walls	1,100 to 1,400
In 13-in. walls	1,300 to 1,600
In 18–22-in. walls	1,500 to 2,200
Heavy foundations	3,000 to ——

Rate of bricklaying. The number of openings, pilasters and corners makes a big difference in the amount of brick laid. Working on narrow piers, projections, etc., a man might find it difficult to lay 500 brick in 9 hrs. The writer knows of one job on which four bricklayers, two of whom were the contractors, were building a 3 ft. wall, the footing for a warehouse. They ran out of brick. Two cars were set one afternoon containing 20,000 brick and the next day the four bricklayers put them all in the wall, an average of 5,000 (kiln count) apiece. No mortar boards were used, the mortar being dumped on the wall and spread with shovels, trowels being used for the outside 4 in. only. In addition to the usual materials two "eighths" of beer were used. How much this increased the rate of laying I am not prepared to say.

Bricklayers are paid all the way from 30 to 70 cts. per hour, but 60 cts. is probably the rate most commonly met with.

To tend each bricklayer, keeping him supplied with brick and mortar and building scaffolds, from one to two laborers are usually

required, receiving from 17½ to 30 or even 40 cts. per hr. where hod carriers' unions have forced the price up. The usual rate is 20 to 22½ cts. per hr.

In buildings having several stories, such as stores, warehouses, etc., where the materials can be dumped on the ground floor, raised to the proper story on an elevator, and distributed in wheelbarrows to the wall, the labor may fall as low as $1 per M. On buildings of this class, only one scaffold need be erected for each story, the joist serving for the lower half of the wall.

On one story factory buildings with high gables where the scaffolds have to be carried all the way up and everything handled in hods the labor will run $2 to $4 per M with laborers at 20 cts.

The cost of getting materials on the ground varies greatly depending on conditions.

In cities where the brick yards are close at hand the brick are usually delivered in wagons by the manufacturers, who make a uniform charge to cover the cost of delivery to any part of the city.

Where the brick have to be shipped in on cars, then unloaded and hauled some distance, the freight and hauling may amount to several dollars per M.

Over good paved streets a team can easily haul 1,500 brick, but over poor dirt roads 500 might make a big load.

Cost of Brickwork in Five One Story Manufacturing Plants.— The following tables give the actual cost of laying something over a million brick in five one-story factory buildings forming part of a large manufacturing plant. Brick cost $5 and $5.25 at the yards, the average price being $5.08.

Materials.

Brick, 918 at $5.08 per M	$4.67
Brick freight	1.12
Sand, ½ cu. yd. at $0.46	.23
Sand freight	.13
Cement, .44 bbl. at $2.00	.88
Lime, 2 bu. at $0.20	.40
Total materials	$7.43

Labor.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	Avg.
Bricklayers	$5.56	$4.49	$4.57	$4.68	$3.68	$4.16
Laborers	1.95	1.67	2.14	1.95	2.00	1.87
Carpenters	.70	.71	.88	1.15	.67	.77
Unloading mat'l	1.16	1.16	1.16	1.16	1.16	1.16
Total labor	$9.37	$8.03	$8.75	$8.94	$7.51	$7.96

This makes the average total for materials and labor $15.39. The cost per cu. yd. would be just half this or

Materials.

459 brick at $5.08	$2.34
Brick freight	.56
¼ cu. yd. sand	.11
¼ cu. yd. sand freight	.06
.22 bbl. cement at $2.00	.44
1 bu. lime at $0.20	.20
Total materials	$3.71

Labor.

Bricklayers	$2.08
Laborers	.93
Carpenters	.39
Unloading materials	.58
Total labor	$3.98
Total materials	$3.71
Total material and labor	$7.69

On all the buildings except No. 1 bricklayers were paid 60 cts. per hour and foreman 65 cts. On No. 1 local bricklayers from the town near which the plant was built were used at 50 cts. per hour. They proved too expensive, however, and for the balance of the work bricklayers were imported from a large city at 60 cts.

The hodcarriers and mortar men were developed from local laborers and paid 17½ cents per hour.

Buildings No. 1 and 2 were long and low, containing about equal amounts of 9 in. and 13 in. walls.

Buildings Nos. 3 and 4 were higher and contained a somewhat larger proportion of 13 in. walls. Part of the brick work in No. 4 started from steel lintles at some distance above the floor line, which explains the higher cost of scaffolding.

Building No. 5 was higher than any of the others and contained more brick. It was composed of 13 in. walls, with some 18 ins. and 22 ins., which accounts for the lower cost of laying, although better foremanship was responsible for part of this.

The scaffolds were erected by carpenters at 20 and 22½ cts. per hr., drawn from other parts of the work when needed.

The cost of unloading the brick, sand, lime and cement was all charged under one head, $1.16 being the average for the job. Teams were paid 30 cts. per hour. The materials had to be hauled an average of ⅓ of a mile over country roads.

Allowing $0.85 as the proper proportion to charge to unloading the brick, their cost delivered on the ground would be

$5.08 plus $1.12 freight plus $0.85 hauling equals $7.22 per 1000.

If this work were figured by the rules frequently used by masons, (22¼ brick per sq. ft. of 13 in. wall, openings included) the cost per M. would be about $12.75 instead of $15.39.

Cost of Powerhouse Brickwork in Indiana. The following costs of the brickwork for an electrolytic lead refining plant at Grasselli, Ind., are taken from Engineering and Contracting, Mar. 12, 1913.

The brick walls of the power house were about 34 ft. high and the walls were 13 ins. thick. There were about 240,000 brick laid and the work was done between June 11 and July 19. Ordinary scaffolding was built up and materials were hoisted with a light apparatus operated by a single horse. Wages were 75 cts. per hour.

Brick laid	240,000
Total labor cost	$1,838.12
Cost per M brick	7.66

The brickwork for the tank house consisted of walls about 30 ft. high and 13 ins. thick. There were 360,000 bricks in all and they were laid in about 26 days with the same scaffolding that was employed on the power house.

Brick	360,000
Total labor cost	$2,054.20
Labor cost per M	5.70

Cost of Laying Common Brick and Fire Brick in a Foundry Building. Victor Windet (Engineering and Contracting, June 28, 1911) gives costs for the Chicago Drop Forge & Foundry Co.'s hammer shop, which was built of 13 in. and 17 in. common brick walls some 30 ft. high from floor to roof, and required 100,000 brick in its construction. The actual bricklaying cost $4.29 per 1,000 brick, or 6.36 hours. The collateral operations of unloading brick, mortar, scaffold work, etc., cost $2.88, or 7.24 hours. A bricklayer's average 8-hr. day's work was the laying of 1,257 brick. The cost of brick, mortar materials, coping and lumber for scaffolding was $8.90 per 1,000 brick, making a total cost of $16.07 per 1,000 brick. If the scaffolding, horses, mortar boards, etc., had been available from some other work, this cost would have been reduced $1.40 per 1,000 brick.

An old wall 13 ft. high was taken down, and the brick were cleaned and piled at a cost of $0.56 per thousand.

A smooth red brick made at Hobart, Ind., not quite as fine as the pressed red brick available in the Chicago market, makes a very presentable wall. On account of its finish, more care is required in laying than is the case with the Chicago common brick. In building a power house 220 ft. long and 30 ft. high of side walls, using a 13-in. wall with plain pilasters at the steel columns and corners, and three smaller buildings adjacent, 370,000 brick were laid at the following costs for labor:

			Per 1,000 brick.	
	Hours.	Cost.	Hours.	Cost.
Bricklayer foreman	337	$ 269.60	0.91	$0.72
Bricklayers	3,863	2,607.87	10.5	7.05
Helpers	4,285	749.85	11.6	2.02
Mortar mixers	717	154.15	1.94	0.40
Labor foreman	175	61.25	0.5	0.16
Labor (common)	2,078	363.65	5.68	0.97
Hoist operator	120	42.00	0.33	0.10
Carpenter foreman	85	42.50	0.03	0.11
Carpenters	324	113.40	0.90	0.30
Handy man	190	46.50	0.51	0.12
Timekeeper	185	55.50	0.50	0.15
Total	12,359	$4,506.27	33.4	$12.10

Teaming of scaffold, etc., to and from work and unloading of brick and sand from cars not included. Cost of washing walls inside and outside with acid is included. One-half of the work was done with scaffolds hoisted by cables and winches as the rise of the brick work required. The rest of the scaffolding was the ordinary wooden staging.

Laying of Fire Brick. In the building of a blast furnace plant

640,000 fire brick were used in the construction of gas flues from the hot blast stoves and boilers to the chimneys, and also for foundations of two blast furnaces. The flues were composed of 9-in. walls and arches and 4½-in. floors. As the flues were subsequently imbedded in massive concrete foundations, forms were built on the interior lines of the flues throughout. The fire brick laid in neat Portland cement grout were laid against the forms and then the concrete was built against the brick. The joints averaged 1/16 in. to ⅛ in. thickness. Half of the cost of the forms was charged against the brickwork. Due to the presence of the forms, the masons laid brick much faster than if they had to build a wall by plumb and line, or against the concrete while working in the interior of the flues. The floors were paved with brick on edge laid on 2 ins. of sand and grouted. The blast furnace foundations were in courses 3 ft. high and 9 ft. to 12 ft. thick.

TABLE XIX. FIRE-BRICK MASONRY LABOR

	Brick laid.	Masons' hours.	Helpers' hours.	Brick mason per day.	Cost per 1,000 brick.
Arches of flues........	63,930	530	2,380	1,206	$14.45
9-in. walls of flues.....	232,395	490	4,450	4,110	6.48
Paving of flues........	32,580	221	1,320	1,480	14.40
Total	328,905	1,241	8,150	2,652	$ 8.73
Massive foundations ..	311,495	1,150	5,600	3,386	6.85
Total or average....	640,400	2,391	13,750	2,720	$ 7.81

FIRE-BRICK SIZES

Kind.	Vol. of brick cu. in.	Brick per cu. ft.	⅛-in. joints brick per cu. ft.	Brick laid.
8 7/16 x 2½ x 4 1/16	85.6	20.2	18.3	539,000
9-in. Straight 8 7/16 x 2½ x 4 1/16	79.7	21.7	19.7	60,000
No. 1 Arch 8¾ x 4 x 2 1/16 and 2½.	64.3	26.9	24.2	3,000
No. 2 Arch 8¾ x 4 1/16 x 1½ and 2⅛	67.8	25.5	23.2	10,000
No. 1. Key 8½ x 2½ x 2⅜ and 4.	72.6	23.8	21.7	2,700
No. 2. Key 8½ x 2½ x 3 and 3⅞.	69.4	24.9	22.7	25,000
No. 3 Key 8½ x 2½ x 2½ and 4..	63.8	27.1	24.5	1,700
No. 4. Key 8½ x 2½ x 2 and 4...				
Total				641,400

Unloading brick from box cars and carefully piling took 5 hours at $1.12½ per 1,000 brick. The wages for an 8 hour day were as follows: Masons, $7; helpers, $2.50, and foreman, $3.75.

The exterior foundations of two blast furnaces was massive work. The form and dimensions of the work were such as to be exceedingly favorable to low costs. The brick were taken from cars on tracks immediately adjacent and parallel to the work. The mortar was 1:1 mixture of Portland cement and sand, and was mixed into a thin grout. This was poured over the brick from one quart dippers and the brick was laid with joints varying from nothing to ⅛ in. in thickness. About 5 per cent. of the brick laid in the gas flues

were laid as headers to project 4 ins. into the concrete which was afterwards built up around it.

Including unloading brick, mortar men, tenders, carpenters, or forms, and other laborers, there were ten men per bricklayer.

The average 9-in. straight fire-brick is 9 x 4½ x 2½ containing 101.25 cu. ins., with rubbed joints; this will take 17 brick per cu. ft. of masonry.

Cost of a Pump-Pit. Mr. P. E. Harroun (Transactions of American Society of Civil Engineers, January, 1905) gives the following data on excavating a circular pump-pit 26 ft. deep and 22 ft. in diameter. The work was done in Porterville, Cal., in 1904, by company labor which was not efficient, and was high priced. In sinking the pit, the upper 8 ft. were river silt, then came 5 ft. of coarse gravel carrying a large volume of water, and the remaining 13 ft. were in clay. The clay was very hard to pick, and contained many seams carrying water. The sides of the pit were covered with spouting streams and the bottom of the pit was a series of small geysers. On account of the sloughing of the sides, it was necessary to timber the pit from top to bottom. The timbering consisted of 4 x 12-in. rangers or wales, and braces, sheeted with 2-in. plank driven vertically, as in sewer work. The earth was loaded with shovels into dump boxes, holding ⅓-cu. yd. each, and raised with a derrick, the hoisting power being a pair of mules. One box was loaded while the other was being dumped into a wagon. The following costs do not include the hauling away in wagons or the cost of dumping the pit:

	Per cu. yd.
Laborers, at 20 cts. per hr.	$0.58
Team of mules, at 20 cts. per hr.	0.06
Foreman of laborers (130 hrs.), at 30 cts.	0.08
Tools and blacksmithing	0.14
Lumber (7¼ M, at $22)	0.36
Miscellaneous material	0.04
Carpenter (160 hrs.), at 35 cts.	0.11
Carpenter's helper (154 hrs.), at 20 cts.	0.07
Foreman of timbering (130 hrs.), at 30 cts.	0.08
Total per cu. yd., for 454 cu. yds.	$1.52

It will be noted that the carpenter work, including helper, cost $11.50 per M of timber. There were 10 laborers, 1 team of mules, and 1 foreman, at work about 13 days (10-hr.), doing the excavating.

A circular reservoir 4 ft. deep and 52 ft. in diameter was excavated in stiff adobe (clay), and about 300 cu. yds. were loaded with pick and shovel into wagons and hauled away. The cost of this pick and shovel work alone was 59 cts. per cu. yd., wages being 20 cts. per hour.

Building Costs for Electric Light and Power Station. W. H. Weston (Engineering Magazine, Jan., 1912) states that electric light and power stations usually average $2.75 to $3 per sq. ft. of floor area. For water-power plant buildings, not counting any expense of foundations that may or may not be necessary, amount to

$2.75 per sq. ft. of floor area. Water-works pumping stations vary from $3 per sq. ft. for the plain buildings to $6 for the ornamental ones, and more than this with elaborate architectural features.

Car barns with steel columns and roof cost from $0.08 to $0.10 per cu. ft., making the height from basement floor to average roof and all measurements to the outside of walls. Boiler shops with structural steel columns and framing and steel roof trusses, galleries with heating and ventilating equipment cost from $2 to $2.25 per sq. ft. of the area of the first floor.

Cost of Buildings for Compound-Condensing Steam Plants without Chimneys. W. H. Weston also gives the following table:

H.p.	Engine and boiler.	Foundations for engines, condensers and pumps.
400	$ 7,000	$ 1,400
500	7,500	1,800
600	7,800	2,200
800	8,500	2,800
1,000	9,500	3,400
1,500	13,500	4,800
2,000	17,000	6,000
4,000	30,000	10,000

Cost of Street Car Barns. H. T. Campion and William McClellan in a paper on "The Design of Railway Structures," read before the American Street and Interurban Railway Association, give the following approximate costs of different types of car barns and shops:

	Cost per sq. ft.
Timber barn, 2-track bays, sides covered with corrugated iron	$0.55 to $0.70
Timber barn, 3-track bays, brick or stone walls	1.10 to 1.30
Fireproof concrete barn, 3-track bays, concrete or brick walls	1.25 to 1.50
Clear span steel roof, 8 to 10 tracks, brick walls	1.40 to 2.00

Cost of Electric Railway Car Shops. W. L. Fulton (Engineering and Contracting, October 6, 1915) describes an addition to the shops of the Omaha & Council Bluffs Street Railway Co., Omaha, Neb., comprises a one-story section 134 ft. 8 ins. wide and 144 ft. 8 ins. long, and an adjoining two-story section 80 ft. wide and 112 ft. 8 ins. long. The building was built by the company to provide facilities for the construction of street cars, and it houses the wood-working department, or mill room, and the car-erecting and car-painting departments. The wall footings and the walls up to the first floor level are concrete; above this level the walls are brick. The steel roof trusses are of the saw-tooth type; they are supported on interior steel columns and on the brick walls.

Loads and Allowable Stresses. In designing the structure the following loads were used:

Loading.	On roof, lbs. per sq. ft.	On second floor, lbs. per sq. in.
Dead load	10	15
Snow load	15	...
Live load	25	100

The allowable pressure on the clay and loam soil was 2,000 lbs. per sq. ft.

General Design Features. It will be noted that the central portion of the two-story section, embracing an area 32 x 80 ft., is open from the first floor level to the roof; the remaining area is provided with a second floor consisting of a 2 x 6-in. matched yellow pine flooring laid on 3 x 12-in. wooden joists, the joists resting on 18-in. 55-lb. I-beams. The roof sheathing is also 2 x 6-in. matched yellow pine, and is spiked to 3 x 10-in. and 2 x 10-in. yellow pine purlins bolted to clip angles. The skylight windows in the vertical (north) sides of the saw-tooth roof provide excellent lighting facilities. To provide for ventilation some of these skylight windows are arranged to open by means of sash-operating devices manipulated from the floor level.

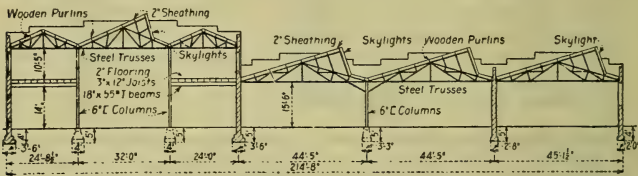


Fig. 9. Cross-section of addition to Lake St. shops of O. & C. B. St. Ry. Co., Omaha, Neb.

Excavation. The ground surface at the site sloped gently from northwest to southeast, the building facing the east. The site was excavated to a level 8 ins. below the first floor, with an elevating grader, the average cut being about 2 ft. 9 ins. The excavated material, consisting of clay and loam, was hauled away in dump wagons, the average length of haul being 1,140 ft. The total excavation was 2,852 cu. yds.

TABLE XX. COST OF EXCAVATING BUILDING SITE

Item.	Rate per hour.	Cost per cu. yd.
Foreman	$0.325	$0.0045
Elevating grader:		
Driver	0.225	0.0032
Operator	0.225	0.0032
Driver	0.20	0.0028
Teams	0.15	0.0147
Wagons:		
Drivers	0.20	0.0228
Teams	0.15	0.0171
On the dump:		
Scraper team	0.15	0.0021
Dumpman	0.225	0.0032
Leveling site after excavation:		
Driver	0.225	0.0020
Teams	0.15	0.0024
Total cost		$0.0780

The trenches for the wall footings were excavated by hand. These trenches varied from 2 to 4 ft. in width and from 4 to 7 ft. in depth. A total of 416 cu. yds. was excavated, of which 312 cu. yds. were loaded into dump wagons and hauled to a dump 400 ft. distant. In loading the earth into the wagons it was thrown onto the bank by the digger and was shoveled into the wagon by a second man. The team and driver were idle while the wagon was being loaded. The cost of excavating 416 cu. yds., including the loading of 312 cu. yds. into wagons, is given in Table XXI.

TABLE XXI. COST OF EXCAVATING FOR WALL FOOTINGS

Item.	Rate per hour.	Cost per cu. yd.
Foreman	$0.25	$0.032
Labor	0.20	0.251
Total		$0.283

The cost of hauling 312 cu. yds. to the dump, a distance of 400 ft., was $34, or 10.9 cts. per cubic yard. This includes the cost of the teams and drivers, but does not include any charge for the foreman. The rates of pay for teams and drivers were respectively 15 cts. and 20 cts. per hour.

Mixing and Placing Concrete. The concrete in the wall footings and in the walls below the first floor level was mixed in a ½-cu. yd. mixer driven by a gasoline engine and equipped with a charging hopper. The concrete was mixed in the proportions of 1 part cement, 3 parts sand, and 5 parts broken stone. The stone and sand were wheeled to the mixer from stock piles. The concrete was wheeled from the mixer to the forms in barrows of 3 cu. ft. capacity, the average distance wheeled being 105 ft. The cost of mixing and placing 315 cu. yds. of concrete is given in Table XXII.

TABLE XXII. COST OF MIXING AND PLACING CONCRETE IN FOOTINGS AND IN WALLS BELOW GRADE

Item.	Rate per hour.	Cost per cu. yd.
Foremen	$0.30	$0.033
Wheelers:		
Stone	0.20	0.106
Sand	0.20	0.065
Cement	0.20	0.179
Placing concrete	0.20	0.036
Handling cement	0.20	0.034
Charging mixer	0.20	0.036
Discharging mixer	0.20	0.036
Total cost		$0.525

Concrete Wall Forms. The concrete walls below grade are 17½ ins. thick and have an average height of 3 ft. 8 ins. The total area of forms was 6,450 sq. ft. The forms were used twice and contained 8,500 ft.; they were built of 2-in. plank, cleated together, and were handled in sections. The forms were built in place in

their first location, and after a section of wall was completed they were removed by the men and immediately set up in their second location. The costs of building, setting and removing the forms therefore were not separated, the combined cost being as given in Table XXIII.

TABLE XXIII. COST OF BUILDING, SETTING AND REMOVING WALL FORMS

Item.	Rate per hr.	Cost per M ft. b. m. (18 M ft.)	Cost per cu. yd. of concrete (227 cu. yds.)
Foreman	$0.55	$1.02	$0.076
Carpenters	0.45	6.25	0.468
Helpers	0.295	2.44	0.183
Total	....	$9.71	$0.727

Brick Laying. Common bricks only were used, and these were laid in 1 : 2 Portland cement mortar, with just enough lime added to make the mortar work easily. The mortar was hand mixed. The brick and mortar in the first-story walls were conveyed in wheel-barrows, inclined runways having been built from the ground to the scaffold level. Except in the two-story section the first-story walls have a uniform thickness of 17 ins. In that section the first-story walls are reinforced on the inside with pilasters 8 ins. thick and 17 ins. wide, these pilasters being spaced 16 ft. on centers. The second-story walls are 13 ins. thick and are reinforced at the trusses with 8 x 17-in. pilasters on the inside and 4 x 17-in. pilasters on the outside of the walls. The brick and mortar for the second-

TABLE XXIV. UNIT AND TOTAL COSTS OF LAYING BRICK WALLS

		First-story walls.		Second-story walls.
Item.	Rate per hr.	Cost per 1,000 bricks.	Total cost.	Cost per 1,000 bricks.
Foreman	$0.80	$0.152	$ 60.80	$0.602
Masons	0.70	3.527	435.40	4.310
Tenders	0.25	1.116	162.00	1.604
Mixing mortar	0.25	0.488	35.00	0.347
Building scaffolds	0.295	0.434	47.85	0.474
Operating elevator	0.30	.....	33.60	0.333
Totals	...	$5.717	$774.65	$7.670

story walls were loaded into wheelbarrows at the ground level, hoisted to the second-floor level, and then wheeled along runways to the scaffolds, as in the case of the first-story walls. The first-story walls contained 310,000 bricks and the second-story walls 101,000. The itemized cost of laying these walls was as given in Table XXIV.

Erecting Structural Steel. The steel frame consists of 6-in. latticed channel columns, 18-in. I-beam floor girders, roof trusses and wind bracing for both columns and trusses. All trusses were delivered entirely riveted up, with the exception of those over the car-erecting and painting shop; these trusses were delivered in two sections. These sections were bolted together on the ground, hoisted to place with a hand-operated breast derrick, and riveted. The second-floor girders were shipped with connection angles riveted to them. 3600 field rivets were required, or 54 field rivets per ton of steelwork. These were driven with pneumatic hammers, compressed air being supplied by a portable air compressor, driven by an electric motor. The weights of the various portions of the steel frame were as follows:

Item.	Lbs.
Columns	13,350
Column bracing	2,700
Girders at second floor	20,500
Roof trusses over one-story section	57,400
Roof trusses over two-story section	13,100
Lateral bracing for one-story section	15,600
Lateral bracing for two-story section	8,750
Total	131,400

The total and unit costs of erecting and riveting the steelwork were as given in Table XXV.

TABLE XXV. COST OF ERECTING AND RIVETING STEELWORK

Item.	Rate per hour.	Cost. per ton.
Foreman	$0.60	$1.53
Labor	0.45	4.89
Total		$6.42

Second-Floor Construction. The second-floor construction consists of 2 x 6-in. matched yellow pine flooring laid on 3 x 12-in. joists, and nailed with 20-d nails, two at each bearing. The joists are 16 ft. long and are spaced 2 ft. on centers. Solid bridging, 2 x 12 ins., was cut to fit between the joists over the I-beams, and one row of 1 x 2-in. cross bridging was placed between the joists at the center of the span. All material was raised to place by hand. In constructing this floor 24,300 ft. b. m. of lumber were used, divided as follows: Joists, 9,700 ft. b. m.; flooring, 14,000 ft. b. m.; and bridging 600 ft. b. m. The total and unit costs of building this floor were as shown in Table XXVI.

TABLE XXVI. COST OF CONSTRUCTING SECOND FLOOR

Item.	Rate per hour.	Cost per M ft. b. m.
Foreman	$0.55	$0.724
Carpenters	0.45	2.963
Helpers	0.295	1.700
Total	...	$5.387

Roof Construction. The roofs were constructed of 2 x 6-in. matched yellow pine flooring spiked to 2 x 10-in. and 3 x 10-in. purlins, the latter being bolted to clip angles on the trusses. The spacing of the purlins varied from 4 ft. to 6 ft. All material was raised to place by hand. For the roof over the one-story section 50,900 ft. b. m. were used, of which 10,600 ft. b. m. were in the purlins and 40,300 ft. b. m. in the sheathing. The roof over the two-story section required 27,500 ft. b. m. of lumber, of which 5,700 ft. b. m. were in the purlins and 21,800 ft. b. m. in the sheathing. The total and unit costs of constructing these roofs were as given in Table XXVII.

TABLE XXVII. TOTAL AND UNIT COSTS OF CONSTRUCTING ROOFS

		One-story section.	Two-story section.	
Item.	Rate per hr.	Cost per M ft. b. m.	Total cost.	Cost per M ft. b. m.
Foreman	$0.55	$ 1.156	$ 41.80	$ 1.520
Carpenters	0.45	6.542	273.60	9.949
Helpers	0.295	2.434	97.94	3.561
Total	...	$10.132	$413.34	$15.030

The higher unit costs for the roof over the two-story section were due to several factors, among which are: the trusses have a shorter span; they have a steeper slope; and the material had to be elevated a greater distance.

General Costs. The cost of this building equipped, per square foot of floor area, was $1.28, divided as follows: Building proper, 86.3 cts.; heating, 5.1 cts.; lighting, 1.1 cts.; sprinkler system, 27.6 cts.; tracks and trolleys, 8.3 cts.

The cost given for heating covers that of an indirect system, including fan, heating coils, galvanized iron air distributing ducts, and supply and return mains (each 440 ft. long); it does not include the cost of the boilers. The cost given for the sprinkler system does not include that of the tanks, but does include all other parts necessary to a dry pipe sprinkler system. The cost per sprinkler head was $6, each head covering an area of 21.7 sq. ft. The tracks consist of 70-lb. A. S. C. E. rails laid on 6 x 8-in. x 7 ft. cross-ties spaced 2 ft. on centers.

Cost of Buildings and Equipment for a Smelter in Arizona. E. H. Jones (Bulletin of the American Institute of Mining Engineers, July, 1914) gives the following costs for the Arizona Copper Co. plant at Clifton, Ariz.

TABLE XXVIII. COST OF SMELTER BUILDINGS PER SQUARE FOOT

Name of building.	Floor space, sq. ft.	Cost per sq. ft.	Cost per sq. ft., equipped.
Crushing plant	1,650	$3.62	$ 5.62
Sampling plant	6,140	2.65	5.56
Roasting plant	28,740	1.51	4.76
Reverberatory plant	20,370	2.49	8.45
Reverberatory boiler building...	14,310	2.58	11.16
Converter building	26,084	3.34	8.28
Boiler and blacksmith shop.....	4,424	2.56	4.85
Machine and carpenter shop....	5,144	2.90	5.32
Warehouse	5,040	2.28	2.70
Laboratory	1,492	2.92	4.12
Sample room	600	1.65	4.71
Power plant	32,096	2.41	11.20

TABLE XXIX. COST OF SMELTER BUILDING PER CUBIC FOOT

Name of building.	Volume, cu. ft.	Cost per cu. ft.	Cost per cu. ft. equipped.
Crushing plant	27,040	$0.22	$0.34
Sampling plant	80,547	0.20	0.42
Roasting plant	410,140	0.11	0.33
Reverberatory plant	474,350	0.11	0.36
Reverberatory boiler building..	500,850	0.07	0.32
Converter building	1,529,636	0.06	0.14
Boiler and blacksmith shop....	86,268	0.15	0.24
Machine and carpenter shop....	100,308	0.15	0.27
Warehouse	83,160	0.14	0.16
Laboratory	16,140	0.27	0.38
Sample room	6,000	0.16	0.47
Power house	784,000	0.10	0.46

Miscellaneous Costs. The cost of the cooling tower per 1,000 gal. per min. (capacity 12,000 gals. per min.) was $2,189.42, its total cost being $26,273.01.

The cost of the power plant, including boiler plant, per indicated h. p. (capacity 10,660 i. h. p.) was $55.32, its total cost being $589,717.16. The capacity, indicated h. p., of the three turbines was 9,460; that of the two Nordberg blowers, 1,000; and that of the single air compressor, 200.

The cost of the power plant, exclusive of boiler plant, per indicated h. p., was $37.40, its total cost being $398,631.17.

The cost of the boiler plant per boiler h. p. (capacity 6.143 h. p.) was $31.11, its total cost being $191,085.99. The total capacity is given by seven waste heat units at 713 h. p. each and three oil-fired units at 384 h. p. each.

Labor Costs of an Underground Pumping Plant. H. B. Ferriss, in Engineering and Contracting, Dec. 13, 1916, gives the following segregated items of cost connected with the construction of an un-

TABLE XXX. TOTAL COSTS OF LABOR AND MATERIALS, QUANTITIES OF MATERIALS AND UNIT COSTS OF POWER HOUSE AND EQUIPMENT

Account.	Labor cost.	Material cost.	Quantity of material.	Total unit cost.
Building.				
Excavation	$7,727.56	$ 69.09	7,313 cu. yds.	$ 1.07
Building foundation piers	1,699.92	1,460.02	231.7 cu. yds.	13.64
Building foundation walls	3,735.78	3,628.81	508.5 cu. yds.	14.48
North tunnel	1,350.79	1,230.37	180.3 cu. yds.	14.32
Concrete drain	205.68	227.37	34.6 cu. yds.	12.52
Basement floor, concrete.	916.41	1,347.78	12,130 sq. ft.	0.19
Basement painting	81.45	48.81	830 sq. yds.	0.16
Preparation of concrete for painting	891.73	42.69	2,459 sq. yds.	0.38
Painting concrete	195.84	301.61	2,459 sq. yds.	0.20
Steel structure	....	....	254.29 tons	93.49
Tile walls	3,856.83	4,510.20	14,343 cu. ft.	0.58
Unloading tile	332.40	0.17	522.70 tons	0.64
Wall coping	372.69	107.05	732 lin. ft.	0.66
Doors, windows and frames	974.38	3,319.93	4,044 sq. ft. opening	1.06
Concrete sills	596.33	120.96	964 lin. ft.	0.74
Ventilators	125.60	439.76	6 ventilators	94.23
Main floor columns.....	236.93	626.44	68 columns	12.70
Main floor slab concrete.	1,267.91	3,341.61	10,210 sq. ft.	0.45
Painting underside of main floor	181.88	147.58	2,679 sq. yds.	0.12
Painting top of main floor	95.56	199.32	1,134 sq. yds.	0.26
Roof, Berger multiplex plate	420.83	3,063.18	214.83 squares	16.22
Roof concrete	1,723.10	958.51	214.83 squares	12.48
Roof tar	172.70	127.73	214.83 squares	1.40
Roof, downspouts and tile drain	286.17	240.44	905 ft.	0.58
Roof painting, underside	692.84	324.55	6,813 sq. yds.	0.15
Roof, P. & B. roofing....	577.68	1,317.08	214.83 squares	8.82
Painting sash	290.09	16.72	299 sash	1.02
Painting woodwork	29.50	4.06	89 sq. yds.	0.38
Equipment.				
Crane	131.89	1,723.27	1 crane	1,855.16
Well grading	1,558.07	517.68	2,600 cu. yds.	0.80
Shaft sinking	765.62	612.10	45 ft.	30.61
Timbering	57.61	......	45 ft.	1.28
Aldrich pump installation	74.56	16.62	....	......
Nordberg blowers, foundation	774.06	3,020.83	686.3 cu. yds.	5.53
Nordberg blowers, cost and installation	1,641.62	32,514.02	2 Nordbergs	17,077.82
Nordberg blowers, painting	327.57	57.65	2 Nordbergs	192.61
Turbines, foundation ...	959.08	1,432.70	196.5 cu. yds.	12.16
Turbines, cost and installation	2,297.70	79,586.49	3 turbines	27,294 73
Turbines, painting	286.15	41.02	3 turbines	109.06
Turbines, air pipe making	547.68	200.75	103 ft.	6.27
Turbines, air pipe erection	232.57	64.24	103 ft.	2.88
Transformer trucks and transfer table	121.63	538.08	15 trucks	43.98

Account.	Labor cost.	Material cost.	Quantity of material.	Total unit cost.
Building.				
Auto transformers	735.60	12,044.91	10 transformers	1,278.05
Condenser foundations..	291.08	285.18	50.3 cu. yds.	11.45
Condensers, cost and installation	415.31	19,563.55	3 condensers	6,659.62
Condensers, painting ...	30.00	5.86	3 condensers	11.95
Jet condenser hot well, excavation	28.82	0.90	46 cu. yds.	0.65
Jet condenser hot well, foundation	66.27	69.99	16.5 cu. yds.	8.26
Jet condenser hot well, supporting structure and tank	....	....	5.76 tons	164.18
Jet condenser hot well, cost and erection.....	128.97	494.68	1 condenser	1,078.65
Jet condenser hot well, dry vacuum pumps...	285.51	2,860.01	2 pumps	1,572.76
Jet condenser hot well, pumps, painting	30.00	5.86	2 pumps	17.93
Circulating pumps, foundation	560.04	708.93	210 cu. yds.	6.04
Circulating pumps, cost and erection	366.90	3,535.68	2 pumps	1,951.29
Circulating pumps, painting	30.00	5.86	2 pumps	17.93
Air compressor foundation	840.98	1,246.54	238.3 cu. yds.	8.76
Air compressor, erection	642.90	148.67	....	....
Air compressor, painting	10.58	24.49	....	....
Air compressor, all piping except steam.....	298.46	160.65	....	....
Air compressor, wrecking and transportation ...	457.77	136.06	....	....
Air compressor, installation of air receivers..	49.47	1.43	....	....
2 exciters, 2 air pumps, 2 circulating pumps, foundation	1,439.67	1,875.43	373 cu. yds.	8.89
2 exciters, cost and installation	491.01	6,118.26	2 exciters	3,304.64
3 dry vacuum pumps, cost and installation..	147.26	3,190.10	3 pumps	1,112.45
3 cir. pumps and engines, cost and installation..	389.32	8,729.37	3 pumps	3,309.56
2 exciters, painting.....	86.01	14.65	2 exciters	50.33
3 air pumps, painting...	50.00	8.79	3 pumps	19.59
3 cir. pumps, painting..	81.69	14.65	3 pumps	32.11
2 motor gen., 1 air pump, 1 cir. pump, foundation	269.52	658.91	107 cu. yds.	8.93
2 motor generators, cost and installation	319.06	6,830.33	2 generators	3,574.69
2 motor generators, painting	30.00	5.86	2 generators	17.93
Transfer table pit, concrete	24.13	58.23	12 cu. yds.	6.86
Switchboard, concrete compartments	1,472.21	510.48	1,469 sq. ft.	1.35
Switchboard, cost and erection	2,730.53	15,520.57	....	....
Steam piping north and south mains, excavation	249.65	....	279 cu. yds.	0.89

Account.	Labor cost.	Material cost.	Quantity of material.	Total unit cost.
Building.				
Steam piping, foundation	578.24	945.97	194.5 cu. yds.	7.84
Steam piping, steel supporting structure	....	....	86.81 tons	88.64
Steam piping, hangers and anchors	1,030.68	337.26	153 rods	8.94
Steam piping, cost and erection	2,286.31	18,622.25	3,401 ft.	6.15
Steam piping, covering and erection	266.71	5,813.23	3,401 ft.	1.79
Exhaust pipe, cost and erection	1,745.71	8,715.66	1,541 ft.	6.79
Exhaust pipe, painting..	85.05	51.19	1,541 ft.	0.09
Exhaust pipe, covering and erection	318.25	830.56	746 ft.	1.54
Air piping, cost and erection	363.19	554.16	....	....
Air piping, painting.....	31.56	18.66	....	....
Exhaust pipe, foundation	63.09	102.81	18.3 cu. yds.	9.07
Exhaust pipe, supporting structure	197.27	57.93	....	....
Exhaust pipe, excavation	20.82	....	29 cu. yds.	0.72
Water pipe, excavation and backfill	1,485.10	0.24	2,406 cu. yds.	0.62
Water pipe, cost and erection	3,747.79	16,437.88	....	....
Water pipe, painting....	230.59	25.54	....	....

derground pumping plant. In order to understand the records a brief description of the plant is perhaps necessary.

The company owns a subdivision for which it purchases water in bulk. The normal pressure as supplied to the company is satisfactory up to elevation 140 only. A considerable portion of the subdivision lies above this elevation, and in order to give adequate pressure to the purchasers within this high level district the pumping plant was constructed.

The engineer's original scheme consisted of the usual elevated tanks, etc., but was changed owing to the owner's set policy of placing all utilities underground. The plant, as finally approved by the directors, consists essentially of two electrically driven pumps connected to 2 large tanks; 2 motors operating the pumps; an automatic sump-pump and an air compressor with self-contained motors; all housed within an underground concrete vault. The sump-pump is mounted on an iron bracket fastened to the walls of the vault. The rest of the equipment is placed on raised concrete foundations, with the exception of the tanks, which rest on the floor, part of which was strengthened for this purpose. The plant is connected to large municipal mains and is entirely automatic in its operation.

The vault housing the machinery and tanks is built of 1:2:4 concrete with a percentage of hydrated lime. The work was done very carefully in order to make the vault as nearly watertight as possible. The roof is 5 in. thick of reinforced concrete, supported on "I" beams. The floors are 6 ins. thick, surfaced with 1 in. of

1 : 2 mortar, except under the tanks, where the floor is 12 ins. thick. All openings for pipes, etc., were carefully caulked and the vault is considered practically watertight.

The excavation for the vault was in stiff white clay, and no timbering was required, nor was there any difficulty with water. The

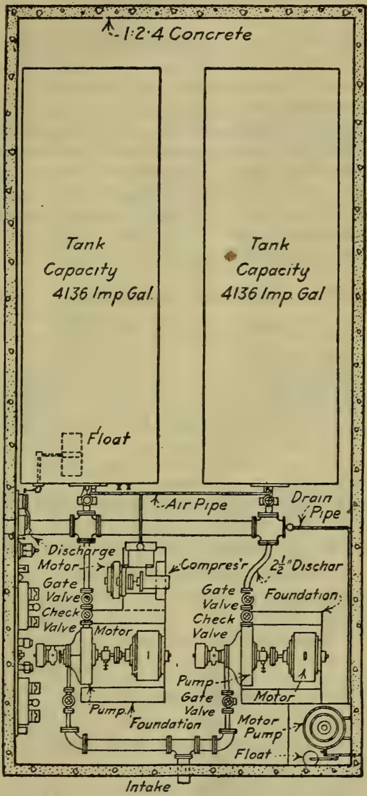


Fig. 10. Underground pumping plant.

dimensions of the excavation were 18 x 38 ft. x 11 ft. deep, or 281 cu. yds., including the sump-hole. Of the total earth removed, 200 cu. yds. were back-filled, 150 cu. yds. were hauled to a dump 1 mile away, and 111 cu. yds. to a dump half a mile away, both hauls over good pavements. Two large boulders were removed during the work. The wagons were loaded as the earth was removed. Weather was good and the work very well handled.

The materials for concrete were delivered conveniently near the work, mixed on top at one end, and handled in wheelbarrows. After the forms and reinforcement were placed the walls were brought up in one continuous operation. The floor was laid first and special precautions taken to secure a good bond with the walls, which were built two or three days later. The workmanship was excellent.

A good foreman and well organized crew were employed from the first and it is believed that the costs on excavation and concrete are close, considering the character of the work.

The cost of installing the machinery, electrical equipment, etc., however, is regarded as high, as the men employed for this work were slow, although thoroughly competent and conscientious. Also there was considerable delay over the delivery of some special castings and other parts of the equipment. The company, however, was not affected, as the work was done under contract. It should, therefore, be mentioned that in the following costs the rates for this part of the work are assumed. The hours are correct.

LABOR COSTS OF CONSTRUCTING UNDERGROUND PUMPING PLANT.

(Excavation (281 cu. yds.).		Per cu. yd.
Foreman, 80 hrs. at $0.50	$ 40.00	$0.14
Labor, 570 hrs. at $0.25	142.50	.50
Teams, 120 hrs. at $0.70	84.00	.30
Blacksmith, 20 hrs. at $0.30	6.00	.02
Backfill and clean-up, 55 hrs. at $0.25	13.75	.05
Total	$286.25	$1.01

Note: Two extra dump wagons were included in the above rate of 70 cts. for teams, which were loaded while the teams were traveling. The unit cost for backfill only was about 40 cts. per cu. yd.

Concreting, including foundations — 57 cu. yds.

Forms and Reinforcement.		Per cu. yd. concrete.
Carpenter, 35 hrs. at $0.40	$ 14.00	$0.25
Helpers, 100 hrs. at $0.35	35.00	.61
Common labor, 44 hrs. at $0.25	11.00	.19
Total	$ 60.00	$1.05
Foundations for Pumps and Motors — Concrete.		
43 hrs. at $0.30	$ 12.90	$0.23
Walls, Floors, and Roofs.		
Foreman, 12 hrs. at $0.50	$ 6.00	$0.10
Mixing, etc., 300 hrs. at $0.30	90.00	1.58
Tamping, 53 hrs. at $0.30	15.90	.28
Miscellaneous labor, 20 hrs. at $0.30	6.00	.11
Mix boards, etc., 10 hrs. at $0.35	3.50	.06
Total	$121.40	$2.13

Installation of Equipment.

Tanks (set in place by contract)		$ 25.00
Erecting all machinery, including water connections, etc.:		
Skilled labor, 200 hrs. at $0.50	$100.00	
Helpers, 240 hrs. at $0.40	96.00	196.00

Painting fittings and general clean up:		
Helpers, 22 hrs. at $0.40	8.80	8.80
Erecting switchboard, wiring, etc., etc.:		
Skilled labor, 192 hrs. at $0.50	96.00	
Helpers, 36 hrs. at $0.30	10.80	106.80
Testing equipment:		
Skilled labor, 22 hrs. at $0.50	11.00	
Helpers, 22 hrs. at $0.40	8.80	19.80
Total		$356.40

General Miscellaneous Labor.

Haul machinery and supplies (other than concrete materials and tanks)	$37.50
Seeding ground over roof of plant	3.50
Removal of tools, etc., and general clean up	11.50
Water connections for mixing concrete	5.50
Miscellaneous labor	15.60
Total	$73.60

The foregoing are all net labor costs only. Overhead inspection, etc., etc., are not included.

Construction and Cost of a Reservoir and Pumphouse. G. F. Alderson in Coal Age, Sept. 23, 1916, describes a reservoir and pumping equipment installed as a means of raising the pressure in a system which under normal conditions, was 20 lbs., to a pressure of 80 lbs. for fire protection purposes.

By referring to Fig. 11 the scheme of the new system may be seen at a glance. The reservoir is filled from the source of supply through the inlet pipe *A*. The floor of the reservoir drains toward a sump *B*, in which is placed the foot valve and strainer on the suction end of the pump. Normally, the valves at *C* and *E* are closed and the valve at *D* is open. Thus the reservoir is shut off from its supply, except in case of fire, when the valve at *D* is closed and valves *C* and *E* are opened. These valves are controlled by a single handwheel within the pumphouse. Should a fire alarm be turned in, the pump is started by throwing the switch at the board *F*. The valves *C* and *E* are opened, and the valve at *D* is closed. In starting the motor, the pump is primed automatically by means of a priming tank placed above it in the pump house. Immediately the pump begins to draw the water from the reservoir and pump it to the discharge *I* into the main leading to the plant, which action at once increases the pressure in the main up to that necessary for producing the desired result through the firehouse.

When starting the operation, the valve at *C* is opened and the water at ordinary pressure flows into the reservoir, thus virtually increasing its capacity, for perhaps 30,000 gals. has flowed into the reservoir while the pump is drawing out 100,000 gals., and so the water is drawn out much faster than it enters.

The dimensions of the reservoir are 40 x 60 ft. with an average depth of 6½ ft. It was constructed of concrete reinforced with ½-in. square twisted steel rods. The floor of the reservoir is 6 ins. thick and the side walls are 12 ins. thick. Both the walls and the

floor were poured in one continuous operation, thus securing a proper bond. The sump is 3 ft. square and 3 ft. deep. It gives ample room for the foot valve and strainer on the suction pipe and also provides space in the bottom for the collection of sediment. From the bottom of this sump a 4-in. pipe drains into the sewer system. At one side of the reservoir an overflow box is provided from which an 8-in. terra-cotta pipe connects with the nearest sewer.

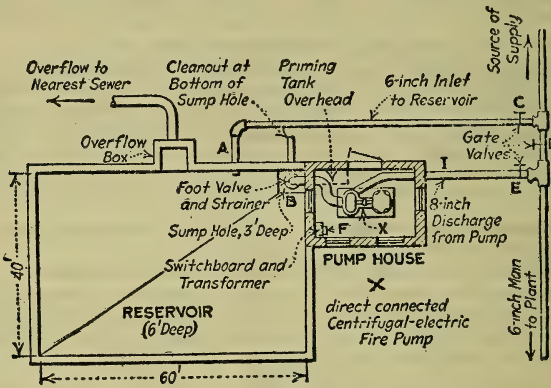


Fig. 11. Piping arrangement for reservoir.

A fireproof pumphouse, 12 x 18 ft., was constructed at one end of the reservoir. This building has a cement floor, brick walls, concrete slab roof supported by an 8-in. I-beam, reinforced with Hy-Rib, and is to house an Allis-Chalmers high-duty, 1,000-gal. electric fire pump, together with all necessary fittings and appliances for its proper operation. The motor was connected to a 2,200-volt service line. The pump running at 1,750 r.p.m. operated under a head of 260 ft. This tank was supported above the pump by brackets on the wall, to provide a means of priming the pump. An automatic ball float valve keeps the tank properly filled.

COST OF ERECTING THE PUMPHOUSE.

Labor, 68%	$536.07	
Masonry (masons at $0.70 per hr., helpers at $0.24 per hr.		$176.04
Forms for roof (carpenters at $0.53 per hr.)		40.78
Carpenter work, setting window and door frames		31.80
Installing pump (plumbers $0.45 per hr., helpers $0.35 per hr.)		129.75
Installing motor (electrician $0.45 per hr., helper $0.35 per hr.)		130.00
Lining tank (coppersmith $0.45 per hr.)		8.50
Painting (painter $0.37½ per hr.)		11.25
Labor at $0.24 per hr		7.95
Material	(32%) 252.16	
Brick (9,000 at $8.50 per M)		76.50
Concrete work, foundation, roof, floor and mortar		53.80

22 bbls. cement $1.30 per bbl., 7 cu. yds. sand $1 per ton, 14 cu. yds. gravel $1.30 per ton.	
Four window frames at $1.75 each	7.00
Paneled door and door frame	3.50
3-in. I-beam 11 ft. 6 in. long	4.00
Lumber forms for roof $20 per M ft. b. m.	20.00
Hy-Rib (270 sq. ft., at $0.022)	6.00
Paint (3 gals., at $1.75)	5.25
Pipe and fittings for connecting pump	71.61
Material for priming tank	4.50
Total cost of pumphouse — Labor	536.07
Material	252.16
	$788.23

To prevent dust and scum from accumulating on the water and to make freezing in winter more difficult, an ordinary sloping roof was built over the reservoir. This roof is supported by nine 8 x 8 in. timbers resting on the floor of the reservoir. For a roof covering, a good quality of 2-ply prepared roofing was used.

The concrete used was a 1:2:4 mixture of Portland cement, clean, sharp, bar sand and clear pit gravel. The concrete was hand-mixed, four boards working continuously until the floors and walls were finished.

COST OF BUILDING THE RESERVOIR.

Labor, 60%	$1,672.23	
Excavation, 804 cu. yds. (labor at $0.24 per hr.)		$ 868.32
Forms for concrete (carpenters at $0.53 per hr.)		230.55
Laying outside piping (plumber at $0.45 per hr., helper at $0.35 per hr.)		71.82
Pouring concrete, 136 cu. yds. (labor at $0.24 per hr.)		422.04
Roof (carpenters at $0.53 per hr.)		79.50
Material, 40%	$1,066.40	
Lumber (average $20 per M ft. b. m.)		248.64
Nails (average $0.017 per lb.)		4.64
Concrete, 1:2:4 mixture		437.22
Cement, 181.25 bbls. at $1.30 per bbl.		
Sand, 56 yds. at $1 per ton.		
Gravel, 112 yds. at $1.30 per ton.		
Reinforcing rods, 9,000 ft. (108 ft. per 100 lbs. at $4 per lb.)		333.00
Wire, No. 12 (200 lbs. at $0.112 per lb.)		22.50
Roofing paper (34 squares at $0.60)		20.40
Total cost of reservoir — Labor		1,672.23
Material		1,066.40
		$2,738.63

CHAPTER IV

CHIMNEYS

Relative Economy of Various Types of Chimneys. There are four types of chimneys in common use: the guyed steel chimney, the self-supporting steel chimney, the radial brick chimney, and the reinforced-concrete chimney. The guyed steel chimney is very commonly used in boiler plants of comparatively small power. It is the cheapest of all types and it has also the most rapid depreciation, as it is generally constructed of light material. Steel chimneys have a shorter life than the brick or reinforced-concrete chimneys, and in some localities, as along the sea coasts or where acid fumes are present in the atmosphere, the depreciation may be very rapid. A maintenance charge exists for steel that is not necessary for brick or concrete chimneys, as they require painting at least once a year if they are to be properly cared for. A brick chimney would naturally be more in harmony with a power house built of brick than any other, and a concrete-steel chimney for a building of reinforced concrete.

As the temperature and friction losses are nearly the same for chimneys of the same height and diameter, irrespective of the material of which they are constructed, the economy of operation of such chimneys is the same, and a selection, on the basis of economy, depends upon their first cost, repair cost, and useful life.

T. J. Maguire in an article in Engineering Magazine, March, 1912, from which the following is condensed gives as an example the case of a power installation where it has been found that a chimney 175 ft. in height and 8 ft. in diameter will be required, and where a careful investigation leads to the conclusion that this chimney will be required for 35 years. A well-designed radial-brick chimney of the above height and diameter would cost about $7,600, and it would readily last the above estimated number of years. The repair item per year for this chimney would be negligible, and the annual cost of the chimney would consist simply of an interest charge on the first cost and the annual sum set aside for depreciation. On the basis of an interest charge of 5 per cent. the annual cost of the radial-brick chimney would be $464.

A reinforced-concrete chimney 175 ft. in height and 8 ft. in diameter would cost about $5,700, if properly designed and installed. Now assume that local conditions are such as to warrant a life of only 25 years, as compared to 35 years for the radial-brick chimney. Evidently the concrete chimney will have to be replaced at the end of 25 years, and as the chimney is required for a total of 35 years, the actual useful life of the second rein-

forced-concrete chimney will be only 10 years. Assuming again that the repair item per year for the two reinforced-concrete chimneys would be negligible, the annual cost for 25 years, for the first concrete chimney, would be equal to $405, and for the second concrete chimney $738, for 10 years. The average annual cost, for the entire 35 years, for the reinforced type of chimney, on the above assumption, would be $500, and the radial-brick chimney would be the more economical type to install even if its first cost exceeds by one-third the first cost of the reinforced-concrete type.

Take, as a third type for this proposed plant, a self-supporting steel chimney, and assume that it will have a life of 20 years, thus necessitating rebuilding once in order to obtain the desired useful life of 35 years. It will be necessary to paint once a year at a cost of about $80 for a chimney 8 ft. in diameter and 175 ft. in height. Assume that the annual cost of the steel chimneys on the average for the entire 35 years is not to exceed the annual cost of the radial-brick chimney, or $464. On this basis, then, the first cost or cost of installing each steel chimney would be equal to $4,410. If the two steel chimneys could each be installed at a cost less than $4,410, then the self-supporting type would be more economical than the radial-brick

A proper selection demands not only a careful comparison of first costs, but also of repair costs, actual useful life of chimneys, and the length of time for which the chimney is desired.

Care should be taken in determining the diameter and height. A chimney larger than the requirements call for is evidently a waste of money, and too small a chimney is likely to prove a very costly investment on account of the deficient draft produced by it and the resulting incomplete combustion of the fuel. The height depends upon the available intensity of draft required of it, and this latter must equal the sum of the draft loss in the breeching connection from boilers to chimney, the draft loss in the boiler setting, and the intensity of draft required in the furnace to burn the fuel properly. The design of the furnace and the grade of fuel that is ever likely to be used during the life of the plant are features that must be carefully considered if the height is to be correctly determined. A well designed chimney of any type will consume 20% of the theoretical draft intensity produced by it, and on this basis the chimney diameter is determined by the maximum boiler horse power which the chimney will have to take care of and the evaporative ability of the fuel used.

The production of draft by a chimney is due to the temperature of the gases in the chimney, and it is therefore evident that a chimney consumes a certain amount of the heat energy of the fuel. A temperature of 475 degs. F. at the breeching connection to the boilers represents good operating economy with the boilers developing their rated capacity, and at 50% overload on the boilers this temperature will rise to 550 degs. F. or higher. In any boiler equipment, whatever may be the design of the boiler and furnace, it is not feasible to lower the breeching temperature to any appreciable extent below the temperatures noted above. It is possible,

however, to abstract further heat from the gases leaving the boilers, by conveying them through an economizer before they reach the chimney. It is not customary, however, to use natural draft in conjunction with an economizer on account of the low temperature of the gases available for chimney purposes. As an illustration take the case of a plant where 0.9 in. of draft at the point where the breeching connects to the stack is required to burn the fuel properly, and assume that the average temperature of the gases entering the chimney is 450 degs. F. If the chimney is at sea level, its height would be 184 ft. in order to satisfy the above conditions. If, now, a suitable economizer were placed between chimney and boilers, with enough heating surface to reduce the temperature of the gases to 250 degs. F., then the chimney would have to create a draft intensity of about 1.1 ins., as the additional draft lost in breeching connections to economizers and in economizer would probably amount to 0.2 in. A chimney 380 ft. in height would be required to produce 1.1 ins. of draft with a gas temperature of only 250 degs. F. Chimneys that are not commercially practicable would be required for use with most economizer equipments, and hence it is customary to employ mechanical draft rather than natural draft for plants using economizers.

Natural draft is very often undesirable for certain coals that are of low heating value, have a high fixed-carbon value, are high in ash, or have a tendency to form objectionable clinkers. For instance, take the case of a boiler plant of 2,000 h.-p. rating, where

TABLE I. CHIMNEY DIMENSIONS FOR VARIOUS HEIGHTS

Height of Chimney.				50 ft.	70 ft	100 ft.	150 ft.	200 ft.
Square Chimney Sides of Square, ins.	Round Chimney, diam. in ins.	Area, sq. ft.	Effective area, sq. ft.	Commercial horse-power of boilers.				
16 x 16	18	1.77	.97	20	30	...	....	....
19 x 19	21	2.41	1.47	35	40	...	....	....
22 x 22	24	3.14	2.08	50	60	...	....	....
24 x 24	27	3.98	2.78	65	80	...	....	....
27 x 27	30	4.91	3.58	85	100	...	....	....
30 x 30	33	5.94	4.48	...	125	...	....	....
32 x 32	36	7.07	5.47	...	150	180	....	....
35 x 35	39	8.30	6.57	...	180	220	....	....
38 x 38	42	9.62	7.76	...	220	260	....	....
43 x 43	48	12.57	10.44	...	...	350	....	....
48 x 48	54	15.90	13.51	...	...	450	550	....
54 x 54	60	19.64	16.98	...	...	565	690	....
59 x 59	66	23.76	20.83	...	...	700	850	980
64 x 64	72	28.27	25.08	...	...	835	1,020	1,180
70 x 70	78	33.18	29.73	...	...	...	1,215	1,400
75 x 75	84	38.48	34.76	...	...	...	1,420	1,630
80 x 80	90	44.18	40.19	...	...	...	1,640	1,900
86 x 86	96	50.27	46.01	...	...	...	1,880	2,200

draft conditions must be such as to enable the boilers to develop an overload of 33½%. Boilers are of the vertical-pass water-tube type, with grate areas equal to 1/32 of the heating surface. The coal that is to be used, to be what is known as anthracite buckwheat No. 3. This coal would have a calorific value of about 11,000 B.t.u. per pound dry, and would run as high possibly as 25% ash. To develop 33⅓% overload, the boiler output would be equal to 2,670 boiler horse power and about 13,500 lbs. of dry anthracite coal would be burned per hour. This would call for a consumption of 22 lbs. of dry coal per square foot of grate per hour, and such a rate of combustion would require a furnace draft of not less than 1.6 ins. With 0.4 in. lost in the boiler and (say) 0.2 in. lost in the breeching, the available draft required would have to equal 2.2 ins. A chimney 96 ins. in diameter and 400 ft. in height would be required. Such a chimney is obviously not practicable on account of its excessive height.

Sizes of Chimneys for Boilers. Table I condensed from one by J. H. Boughton gives the diameters, heights, and effective areas of chimneys, etc., for various commercial h. p. of boilers.

Height and Diameter of Chimney for Plants of Moderate Size (500 h. p. or less) according to C. D. Wesselhoeft (Data, 1914), should be as follows:

	Height, ft.
Free burning bituminous coal	75
Anthracite of medium and large size	100
Slow-burning bituminous	120
Anthracite pea	130
Anthracite buckwheat	150
Anthracite slack	175

For plant of 700 or 800 h. p., the chimney should not be less than 150 ft. high regardless of the kind of coal used.

Internal cross-sectional area of chimney "E" may be obtained from the following formula:

$$E = \frac{3RP}{50\sqrt{H}};$$ in which R = maximum rate of coal consumption in pounds per hr. per rated boiler h. p.; P = total rated boiler h. p.; H = height of chimney in ft. R is commonly taken as 5 lbs., which is high for modern plants.

Cost of Chimneys. W. H. Weston in Engineering Magazine, Jan., 1912, gives the following table figured on a compound condensing basis plus 30% for overload.

H. p.	Cost
400	$2,700
500	3,200
600	3,700
800	4,300
1000	5,100
1500	6,700
2000	8,200
4000	15,000

Cost per Horsepower of Various Chimneys. W. W. Christie (Railroad Gazette, Oct. 19, 1900) gives the following list, Table II, from actual costs.

TABLE II. COST OF CHIMNEYS FOR VARIOUS H.P. RATINGS

Description.	H.-p. rating.*	Cost, dollars. Total	Cost, dollars. Per rated h.-p.	Remarks.
Radial brick, circ....	13,484	40,000	3.00	Foreign.
Red brick, circ.......	4,040	16,000	4.00	
" " "	6,000	18,500	3.00	
" " rect	450	2,192	4.87	
" " hex.	12,211	55,000	4.50	
" " circ	4,859	10,000	2.06	Single shell, firebrick lining half height.
" " "	2,925	15,000	5.13	
" " "	5,772	40,000	6.93	
" " "	6,300	18,500	3.00	
" " "	6,000	25,000	4.25	
" " "	1,100	4,950	4.50	
" " rect.	517	1,900	3.80	
Steel, self-supporting.	2,400	10,000	4.15	Lined throughout.
" "	2,350	8,000	3.40	Half-lined, price without foundation.
" "	240	700	2.91	Unlined.
" guyed	240	400	1.66	"

* Chimney Design and Theory, by W. W. Christie.

Based upon figures given in the table, chimneys of 2,000 h. p. each, if built of red brick, would cost about $8,500 each; of steel, self-supporting, full lined, about $8,300 each; of steel, self-supporting, half lined, about $7,800 each; of steel, self-supporting, unlined, about $5,820 each, 12, $69,840; of steel, guyed, about $4,000 each.

To substitute forced draft apparatus for the large chimney, or chimneys in multiple, there could be used forced or induced draft, or steam blowers. In this connection an 80-in. centrifugal blower, 48 in. wheel, 4 x 3 in. double engine, blower and engine on beam platform, was erected in New England in 1899, connected with a 48-in. diam. chimney of No. 12 steel, 22 ft. high, 10 ft. of it above the roof, 1 in. thick cast base plate. The total cost for apparatus, frame work, and mason work was $856. The boilers used in the plant, in connection with the blower, were horizontal tubular, one 80 in. diam. by 17½ ft.; two 72 in. diam. by 17½ ft. In the same year a self-supporting steel chimney, outlined, 3½ ft. diam.× 105 ft. high, was erected, with foundations and flue connections, at a cost of $1,013. The chimney was made of 3/16, ¼ and ⅜-in. steel. The blower outfit works satisfactorily in the part having two boilers with a total of 75 sq. ft. of grate. The chimney gives a very satisfactory draught for 93 sq. ft. of grate surface, and if it had been made 48 in. diam., as in the blower outfit mentioned, and been guyed with wire rope, with a light foundation, $800 would easily have met the expense. The cost of a double fan outfit, with a short chimney for 1,600 boiler h.p. is given as $3,500, or $2.19 per h.p.

Cost of Mechanical Draft. W. W. Christie (Railroad Gazette,

Oct. 19, 1900) gives the cost of mechanical draft in the table below.

For a good steam plant it is fair to assume the following as average fixed charges for mechanical draft apparatus:

	Per cent.
Interest	5
Depreciation	4½
Insurance and taxes	1½
	11
For a chimney:	
Interest	5
Depreciation and repairs	1½
Insurance and taxes	1½
	8

Then the operating expenses for a mechanical draft apparatus for the plant are, say, $12,000, to which must be added the fixed charges, 11% of cost of outfit, or $5,781, making a total of $17,781, which must be compared with 8% of chimney cost, or $9,600.

Should a cheaper grade of fuel be used there may be an advantage in using mechanical draft. A reduction of over $6,500 per year has been made in actual practice in the case of a boiler plant of 1,000 h.p., by the introduction of mechanical draft, and the burning of buckwheat and yard screenings with a slight mixture of Cumberland coal.

From published tests of steam blowers it is learned that they use from 7.4 to 8.78% of the steam made by the boilers. Eight per cent. of the value of coal used for 24,000 h.p., or $44,474, should be placed in comparison with the operating expenses, $12,000 for mechanical draft, and nothing for the brick chimney, to show the expensiveness of this method.

Design and Quantities for a 220-Ft. Reinforced Concrete Chimney at Penarth, Wales. An unusual type of reinforced concrete chimney has recently been built at Penarth, near Cardiff, Wales, for the new rotary cement plant of the South Wales Portland Cement and Lime Co., Ltd. The following data, descriptive of this chimney, were taken from an article by John W. Rodger, in Concrete and Constructional Engineering in 1914, and is of value for design purposes.

The chimney is 14-sided externally, and is 220 ft. high. It is formed in two parts, the outer shell consisting of concrete blocks, and the inner one being built of brick. The outer and inner shells are not connected at any point throughout the full height of the chimney. The outside and inside diameters of the top of the outer shell are 10 ft. 4 ins. and 9 ft. 6 ins., respectively; the corresponding diameters at the base of the chimney are 20 ft. 6 ins. and 17 ft. 6 ins. Thus the outer shell has a thickness at the top of 5 ins. and at the bottom of 18 ins. The inner shell has an inside diameter at the top of 8 ft. 6 ins. and at the bottom of 9 ft. 2 ins. The thickness for the upper 24.5 ft. of this shell is 4½ ins., and for the lower 183.5 ft. its thickness is 9 ins. The

brick lining is strengthened laterally by brick buttresses which increase in width with the height of the chimney (see Figs. 1, a and 1, b). The minimum clearance between the brickwork of the lining and the concrete shell is 6 ins. This clearance is sufficient to provide for the swaying action of the chimney in a high wind. The estimated maximum deflection of the chimney in an 80-mile-per-hour gale is 3.2 ins. It was realized that the chimney would be subjected at times to exceptionally high temperature, which made it desirable to extend the brick lining to within 12 ft. of the top, and to provide a substantial air space between the concrete and the brickwork as a special protection to the brickwork. Figure 1 (c) shows a detail of one of the reinforced concrete blocks used in the construction of the outer shell; Fig. 1 (d) shows a detail of the top part of the chimney; and (e) shows a detail at *M*, near the base.

The concrete of which the blocks of the outer shell are made is composed of materials in the following proportions: 9 cu. ft. of crushed granite, of a fineness sufficient to pass a ¾-in. sieve, with all dust removed; 5 cu. ft. of clean coarse sand; and 3 cu. ft. of Portland cement. The concrete was mixed by hand, and was molded in cast-iron molds of varying shapes and sizes, care being taken to obtain a wet plastic mixture of such a consistency as could be efficiently worked into the forms to insure a dense concrete. Each block is reinforced with steel rods of varying diameters embedded in the concrete during the process of molding.

The blocks are set in a 1:2 cement mortar with a steel ring, or joint rod, embedded in each horizontal joint and extending around the entire circumference of the chimney. The vertical reinforcement consists of steel rods fixed in the end joints of the blocks, being further protected by concrete "necks" which are molded as a part of the blocks and which form vertical shafts on the finished chimney. Each vertical rod projects a distance of 6 ft. into the concrete foundation, and is attached there to a horizontal steel ring which has a diameter equal to that of the chimney at its base. Special reinforcement is used around and over the flue opening and for the molded cornice and necks.

The lining is built throughout of hard, red bricks, made to the correct radius and set in 1:2 cement mortar, up to the level of the bottom of the intake flue; above that level to the top of the 9-in. brickwork the mortar is composed of ½ part Portland cement, 1 part slaked ground blue lias lime, and 2½ parts sand; while the 4½-in. brickwork — the upper 24.5 ft. of the lining — is set in 1:2 cement mortar.

The chimney rests on a reinforced concrete foundation, consisting of a slab 23.5 ft. square. The load on the bottom course of blocks is 8.5 tons per sq. ft. The total weight of the chimney and its concrete foundation is 1,400 tons, which is equal to a uniform load of 2.54 tons per sq. ft. in the subsoil.

Design, Construction and Cost of a Concrete Chimney at Coldwater, Mich. The design, construction and cost of a concrete

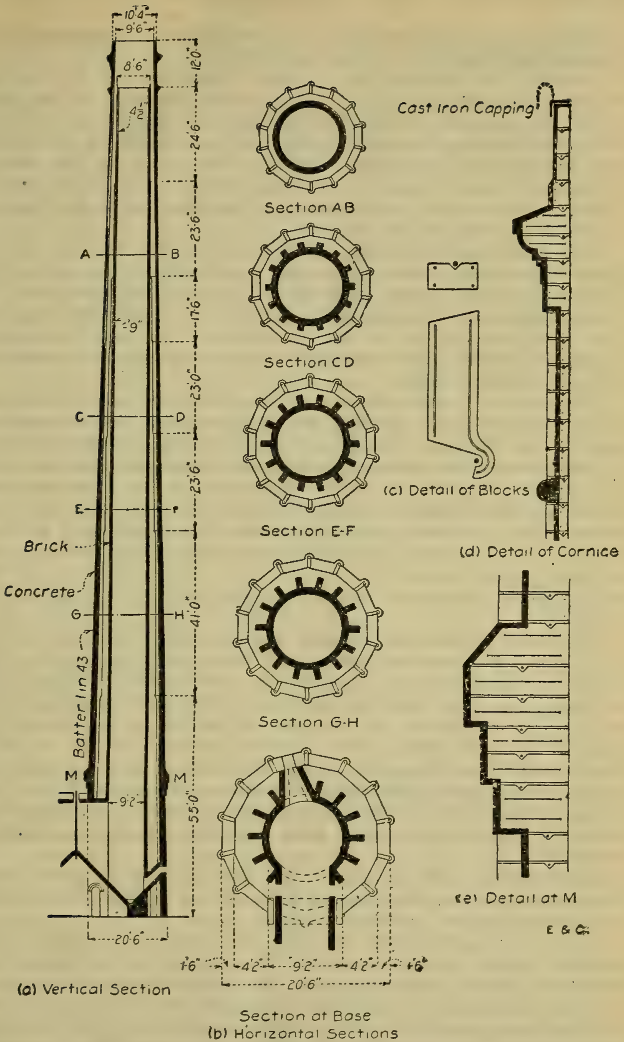


Fig. 1. Sections and details of a 220-ft. chimney.

chimney at Coldwater, Mich., is described in Engineering and Contracting, April 11, 1915, as follows:

Design. The chimney has a total height of 137 ft., an inside diameter at the top of 6 ft., an outside diameter at the top of 6 ft. 10 ins., and an outside diameter at the bottom of 10 ft. The reinforced concrete lining extends to a height of 40 ft. 6 ins., the thickness of this lining being 4 ins., with an air space of 4 ins. between it and the chimney proper. The reinforced concrete foundation has a thickness at its center of 3 ft. 6 ins. and at its outer edge of 1 ft. 6 ins.

The reinforcement in the foundation consists of two layers of bars. The lower layer is placed 4 ins. about the base of the footing, and the upper layer 10 ins. above the lower one. The ¾-in. square twisted bars in the lower layer are placed diagonally, the bars being spaced 12 ins. on centers. The bars in the upper layer are of the same size, these bars being placed parallel to a side on 24-in. centers.

The vertical reinforcement of the chimney consists of ¾-in. square twisted bars, the first set of bars being bent to hook outward under the lower layer a distance of 12 ins. Different lengths of bars were used, and the joints were broken so that the splices did not all come in one form. Beginning at the base, the length of each section and the number of bars used in each are as follows: 7 ft., 72 bars; 12 ft., 62 bars; 15 ft., 52 bars; 15 ft., 42 bars; 18 ft., 32 bars; 20 ft., 22 bars; and 50 ft., 12 bars. The circular reinforcement consists of the American Steel & Wire Co.'s No. 23 triangular mesh, extending the entire height of the chimney.

The shaft around the smoke opening, which is 5 ft. wide by 7 ft. high, is reinforced above and below with three extra rings of ½-in. round bars and on each side with four extra ¾-in. square twisted bars. The head is reinforced with four additional rings of ½-in. round bars. At the top of the lining a shoulder was cast on the outer shell, which projects inward over the top of the lining and 4 ins. above it. This was built to prevent soot from filling the air space, the shoulder being reinforced with two extra rings of ½-in. round rods. The concrete lining is reinforced with twelve vertical ½-in. round bars extending the entire height of the lining.

Construction. The bottom of the footing is 7 ft. below grade, the excavation extending about 4 ins. into a bed of gravel, which was found to give sufficient bearing power.

A 1 : 3 : 6 concrete was used in the foundation, and a 1 : 2 : 4 concrete in the chimney proper. Pit-run gravel was used, as an excellent quality was obtainable. An inspector was constantly on the work, and care was taken to exclude all stones larger than a small egg, especially those of irregular shape. The inspector was furnished with tabular data giving the quantities of materials required for each form, and rigid inspection was insisted on.

The outer surface of the chimney was made smooth by the constant use of a spading bar. At the start the men were re-

quired to repair several rough places on the outside of the chimney, which resulted in a proper use of the spading bar thereafter.

The concrete for the chimney shaft was mixed by hand, while that for the foundation was machine mixed. In hoisting the concrete a rope and bucket were used, a horse being used for power.

All scaffolds were built inside of the chimney. They consisted of four upright posts, each made of two 2 x4-in. x 16-ft. timbers. The ends were butted together and were nailed with 16d spikes, the joints being broken. Around the outside of the four posts, level with the top of the form to be filled, 2x4-in. pieces were spiked, the working platform resting on these. Another set of 2 x 4-in. pieces were placed at a sufficient height to support the sheaves, in order that the concrete could be placed by means of short chutes.

The bucket in which the concrete was hoisted was filled by means of a chute through the clean-out door, the mixing platform being just outside and level with this door.

The forms were constructed of 2-in. lumber, in sections 6 ft. high, the sections being raised to position with ropes.

The chimney was completed in 32 days from the time the foundation was started.

Cost. The following data give the approximate cost of the chimney to the contractor, the wages of the foreman and the assistant foreman being estimated at $6 per day each.

Foreman, 29 days at $6.00	$174.00
Assistant foreman, 35 days at $6.00	210.00
Common labor, 410 hrs. at 20 cts.	82.00
Material: Sand, gravel, cement and reinforcing steel	350.00
Lumber	30.00
Pouring of foundation	25.00
Freight on tools	52.02
Use of horse for hoisting concrete, 23 days at $1.00	23.00
Total	$946.02

The above data do not include transportation for the men, insurance, or depreciation on forms or tools, the total cost of which did not exceed $100. The contract price of the chimney was $1,725.

A Reinforced Concrete Chimney described in Engineering News, Dec. 19, 1901, was built in 1901 by the Ransome Concrete Co. for the Central Lard Co., Jersey City. The stack is 108 ft. high above the foundations, its inner diameter being 8 ft., and its outer diameter 11 ft. 4 ins. The shell is double. The foundation is of concrete, 3 ft. thick, resting on 56 piles driven 55 ft. into marshy ground. The inner shell of the stack is 4 ins. thick. The outer shell is 7 ins. thick at base and 4 ins. at the top. The concrete was 1 part Atlas cement to 5 parts broken trap rock, crusher run, no stone larger than ¾ in. An interior scaffold was built a little in advance of the chimney. The forms, which were in sections 12 ft. high, were suspended by threaded rods passing through band-wheels at their upper ends. A vertical joint in each form was provided with turn-buckles to open or close it.

The air-space between the two shells was made by collapsible boxes.

The following were the quantities:

Concrete in foundation, cu. ft.	1,460
" " stack, cu. ft.	3,514
" total, cu. ft.	4,974
Twisted steel rods, lbs.	8,020
Piles, lin. ft.	3,080

The weight of the chimney, including its concrete base, is 362 tons. The contract price was $3,500.

Cost of Chimney for a Copper Smelter. E. H. Jones (Engineering and Contracting, Dec. 16, 1914) gives the cost of a chimney for the Arizona Copper Co., Clifton, Ariz. The chimney is 300 ft. high, 26 ft. 8 ins. inside diameter at the base and 22 ft. at the top. The average thickness of the walls is 24½ ins. The chimney is corbeled out every 25 ft. to hold the lining of radial perforated fire brick laid in acid-proof mortar. The foundation of the chimney is constructed of concrete, the base of red brick, and the chimney proper of radial blocks. The upper 75 ft. of the chimney are pointed with acid-proof mortar.

The excavation for the foundation was a deep hexagonal cut through clay and caliche, and penetrating a considerable distance into sand and gravel containing large boulders. The material was loosened with picks, slipped out with fresnos, dumped through a trap into carts, and hauled 2,700 ft.

The foundation consists of a concrete block, cast in a hexagonal shape, with a depth of 20 ft. and a least diameter of 50 ft. The bottom of the block is reinforced with three layers of 1-in. rods spaced 1 ft. on centers. The concrete was machine mixed and consists of 1 part cement to 8 parts sand and gravel, with large stones embedded in it. Forms were built for about 40% of the vertical surface. The concrete was transported about 100 ft. in cars.

The chimney proper was constructed by the Alphons Custodis Chimney Construction Co., the costs given including constant inspection by the Arizona Copper Co. There were used in the construction of the chimney proper 138,000 lbs. of lime, 290 lbs. cement, 1,638 tons of radial brick, 652 tons of wire-cut brick, 56 tons of wedge brick, and 100 bbls. of acid-proof mortar.

The cost was as given in Table III.

TABLE III. COST OF CHIMNEY FOR A COPPER SMELTER

		Item	Labor cost.	Material cost.	Total unit cost.
597	cu. yds.	Excavation	$337.44	$ 29.61	$0.61
872.7	cu. yds.	Foundation	654.42	4,199.65	5.56
58,644	cu. ft.	Chimney proper	891.88	39,358.34	0.69
		Total cost of chimney			$45,471.34

Cost of Demolishing a Concrete Chimney in Philadelphia. C. E. Davis (Engineering News, Jan. 14, 1915) gives the cost of

demolishing a reinforced concrete chimney 251 ft. high above ground, with a 91-ft. lower section of 12-ft. outside diameter and 10-in. solid walls and a 160-ft. upper section of 10-ft. outside diameter and 6-in. solid walls. The reinforcement consisted of heavy vertical deformed rods tied by closely spaced circumferential rods of smaller section. The construction was carried on in 5-ft. lifts, which made clear planes of separation; it was here that failure became first evident.

The razing was all done by hand by two and three men on the chimney top breaking down the concrete wall with sledges and bars and throwing the pieces over the side. The reinforcing rods were only lapped at the ends, and thus did not have to be cut or sawed. But very little of the concrete was hard enough to require blasting, but some sections made such difficult bar and sledge work that the wall was loosened up there by small shots.

There was no ladder to the chimney top, so the workmen had to work their way up the inside of the stack by successive short, slanting boards footing into holes dug into the concrete as the lifts progressed. Once the top was reached a line was rigged up by which the men went up and down.

The cost of the work is given in Table IV.

TABLE IV. COST OF DEMOLISHING CONCRETE CHIMNEY, TORRESDALE PUMPING STATION

Cost to demolish first 160 ft.:	
72 men days at $5.00 per day	$360.00
3 men days at 1.75 per day	5.25
	$365.25
Average cost per foot	$2.20
Cost to demolish lower 91 ft.:	
35 men days at $5.00 per day	$175.00
96 men days at 3.50 per day	336.00
36 men days at 1.75 per day	63.00
	$574.00
Average cost per foot	$6.31
Maximum demolished for 1 day in top section 15 ft.	
Maximum demolished for 1 day in bottom section 8 ft.	
Approximate cost to demolish chimney:	
Foremen 59 men days at $5.00	$295.00
Mechanics 48 men days at 5.00	240.00
Mechanics 96 men days at 3.50	336.00
Laborers 39 men days at 1.75	68.25
Rope, tools, powder, etc.	100.00
Approximate total cost	$1039.25
Average cost per foot to demolish	$4.15
Time required to demolish 250 ft., 59 working days:	
Average progress per working day, ft.	4.25
Bid price to demolish was	$2,260

Cost of Demolishing a Concrete Stack from the Inside. O. C. Kern (Engineering Record, June 20, 1914) describes the wrecking of a concrete stack working from inside the stack.

The dimensions of the stack were: Inside diameter at the base, 12 ft. 9 ins., and at top, 7 ft.; wall thickness at the bottom, 12 ins. and at the top, 5 ins. For a height of 75 ft. a lining of radial tile blocks was provided, varying in thickness from 8 to 4 ins. and leaving an air space between the lining and the shell of from 8 to 2 ins. The stack was reinforced vertically with ⅝-in. twisted rods lapped 3½ ft. at all splices, the spacing varying from 3 ins. at the base to more than 3 ft. at the top. These rods were wrapped from top to bottom of the chimney with a single layer of American Steel & Wire Company's 23-mesh wire.

The concrete was broken up with sledges and permitted to fall between the inside of the stack and the tower, the sides of the tower being provided with vertical 1 × 6-in. guard strips to protect the braces, ladders and landings from injury. At all times the scaffold was inclosed with tarpaulin to prevent any injury to the men working below. One man gave his entire time to cutting the wire mesh with a bolt cutter and to tying the ends of the 26-ft. vertical reinforcing rods, so as to prevent their falling when loosened. The rods, which were all saved for use in other work, were lowered to the ground from the outside of the stack. The only accident on the job was occasioned by one of the long rods getting away and falling across the stack, inflicting a slight scalp wound on a workman on the scaffold.

The rods were found to be bright and clean, entirely free from rust. The stack was built in sections about 8 ft. deep, and it was noticed in wrecking that all the joints between sections presented a horizontal plane of cleavage across which the concrete separated with a clean, sharp break. The only cracks found in the entire structure were confined to the 8-ft. bell at the very top. The two largest of the six found showed an opening of nearly ¼ in., disappearing entirely within the depth of the bell. All cracks were vertical.

Every 48 ft. the outriggers were lowered and the upper portion of the tower torn down. This operation required about one day each time and necessitated suspending cutting for part of the day on the upper half, and on the lower half the number of men was reduced, but cutting was not stopped.

Broken concrete and other debris, wheeled in barrows to the fill for a switch track 100 ft. away, was handled by two laborers nights and Sundays. The radial tiles of the lining were saved except for a small breakage and will be used in the lining of the new stack. On the lower 65 ft. of stack it was necessary to use bull points in addition to the sledges in breaking up the concrete, the method being to chisel off 4 to 5 ins. of concrete from the outside into the bars, then to batter off the ledge on the inside of the bars with sledges.

Landings were placed every 48 ft., as it was thought that fatigue of the workmen in climbing to the top of the chimney would interfere with their efficiency. No trouble was experienced, however. The foreman went up in four minutes without stopping, but the laborers were ten minutes in making the ascent,

taking time for rests at the landings. The tarpaulin at the top was partly to prevent the workmen from seeing out and partly for the protection of the men on the ground. Within a very few days these precautions were entirely unnecessary, as the men became accustomed to their dizzy working quarters.

Cost. Laborers were paid 30 cts. an hour and carpenters 40 cts. an hour. The total cost of wrecking 207 ft. of stack and 75 ft. of lining was apportioned as shown in the table.

Omitting the cost of cleaning out the soot and crediting the salvage, the total cost of wrecking the stack amounts to $5.20 per foot of height. Per cubic yard of concrete and tile removed the cost amounts to $4.50. The salvage amounted to more than 8 tons of reinforcing steel valued at $220, 3000 ft. of lumber, $30, and about 1200 cu. ft. of radial tile blocks, $60 — a total of $310.

Liability insurance of $6.48 per hundred was carried in addition to the foregoing costs.

The cost was as follows:

Cleaning out soot below breaching	$ 21.30
Lumber for tower and scaffold. 8,700 ft. B.M.	130.00
Erecting tower 222 ft. high inside stack, building ladders, guard sheeting, platforms, outrigging and scaffold	211.27
Rental on bricklayers scaffold hangers	100.00
Cutting concrete and wire netting, saving reinforcing rods and radial tile lining	649.45
Removing debris, 100 ft. haul, and stacking tile and rods	68.25
Lowering outrigging and tearing down tower	202.26
Total cost of wrecking stack	$1,382.53

The tower was completed in 9 working days and the work of demolishing completed 22 days later.

Dimensions, Lining and Lightning Protection of Radial Brick Chimneys. M. W. Kellog Co. of New York City gives in Engineering News, July 8, 1915, the following data concerning perforated radial brick chimneys:

Lining for Brick Chimneys. The height of the lining for chimneys is found in the following manner: For ordinary conditions, where the temperature does not exceed 800 deg. F., the lining should be approximately one-fifth the height of the chimney; above 800 degs. and below 1200 degs., one-half the total height; above 1200 degs. and below 2000 degs., full height.

Protection against Lightning. For lightning protection two points are the minimum for any chimney of diameter up to 5 ft. Above this, one point should be added for every 2 ft. in diameter or fraction thereof. The points of the conductor should be of copper ¾ in. in diameter by 8 ft. long, with a 1½-in. platinum-covered tip. They should be anchored at the top of the column and extend from the bottom of the corbeling upward. The lower ends of the points are connected by a copper cable which encircles the chimney. From this loop a 1½-in. 7-strand No. 10 Stubs' gage copper cable is carried down the side of the chimney and connected to a copper ground plate of the three-winged type. On

the way up, the cable is anchored every 7 ft. with brass anchors, which support the weight of the cable. The ground plate is buried by the foundation contractor at the time the foundation is built.

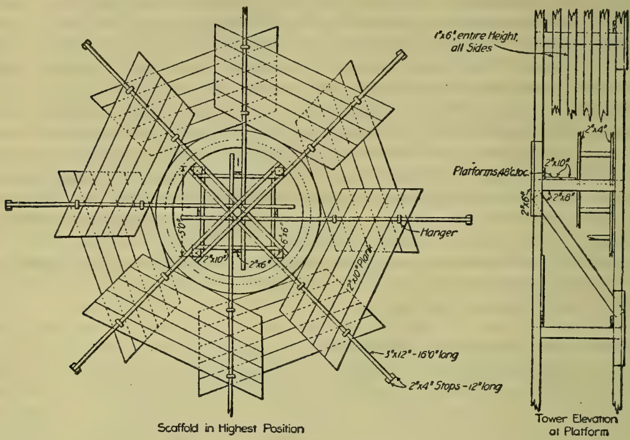


Fig. 2. Outrigging and scaffold for wrecking old concrete stack.

Dimensions. Wall thicknesses of chimneys are obtained from Fig. 3. Table V gives the maximum outside diameter of the chimney at the base, for various heights and inside diameters.

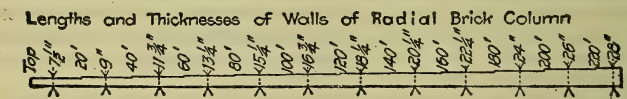


Fig. 3. Dimensions of radial brick chimneys.

TABLE V. DIAMETERS OF RADIAL-BRICK CHIMNEYS

Height of chimney in ft.	Internal diameter at top 3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.
	Diameters in feet at bottom of column							
75......	7.43	7.96	8.96	9.96	....	....	....	....
80......	7.80	8.27	9.13	10.02	....	....	....	....
85......	8.18	8.58	9.31	10.08	....	....	....	....
90......	8.57	8.88	9.48	10.13	....	....	....	....
95......	8.95	9.19	9.66	10.19	....	....	....	....
100......	9.33	9.50	9.83	10.25	11.25	12.25	....	....
105......	9.70	9.85	10.21	10.55	11.50	12.40	....	....
110......	10.06	10.20	10.60	10.85	11.75	12.55	....	....
115......	10.43	10.55	10.98	11.15	12.00	12.70	....	....
120......	10.79	10.90	11.37	11.45	12.25	12.85	....	....
125......	11.16	11.25	11.75	11.75	12.50	13.00	14.00	15.00
130......	....	11.65	12.10	12.13	12.80	13.37	14.22	15.15
135......	....	12.05	12.45	12.51	13.10	13.73	14.43	15.30
140......	....	12.45	12.80	12.90	13.40	14.10	14.65	15.45

Height of chimney in ft.	Internal diameter at top 3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.
	Diameters in feet at bottom of column							
145......	....	12.85	13.15	13.26	13.70	14.46	14.86	15.60
150......	....	13.25	13.50	13.66	14.00	14.83	15.08	15.75
155......	....	13.58	13.87	14.06	14.30	15.06	15.31	15.91
160......	....	13.92	14.23	14.46	14.60	15.30	15.55	16.07
165......	....	14.25	14.60	14.86	14.90	15.53	15.78	16.22
170......	....	14.59	14.96	15.26	15.20	15.77	16.02	16.38
175......	....	14.92	15.33	15.66	15.50	16.00	16.25	16.54
180......	....	....	....	....	15.80	16.30	16.50	16.80
185......	....	....	....	....	16.10	16.60	16.75	17.06
190......	....	....	....	....	16.40	16.90	17.00	17.31
195......	....	....	....	....	16.70	17.20	17.25	17.57
200......	....	....	....	....	17.00	17.50	17.50	17.83
205......	....	....	....	....	....	....	17.80	18.16
210......	....	....	....	....	....	....	18.10	18.50
215......	....	....	....	....	....	....	18.40	18.83
220......	....	....	....	....	....	....	18.70	19.17
225......	....	....	....	....	....	....	19.00	19.50

Cost of Brick Chimneys. J. H. Boughton gives the following table:

Approx. h.-p.	Height, ft.	Diameter flue, inside ins.	Outside dimensions, square base Ft.	Ins.	Outside Wall: No. of brick	Outside Wall: Cost at $14 per M.
85	80	25	7	5	32,000	$448
135	90	30	8	3	40,000	560
200	100	35	9	10	65,000	910
300	110	43	10	2	75,000	1050
450	120	51	11	2	87,000	1218
750	130	61	12	6	131,000	1834
1,000	140	75	13	11	151,000	2114
1,650	150	88	15	1	200,000	2800
2,500	160	110	17	10	275,000	3850

Approx. h.-p.	Cost of fire brick lining, ½ height	Cost of concrete foundation	Total cost of chimney
85	$60	$90	$598
135	82	144	786
200	118	198	1,226
300	190	252	1,492
450	261	306	1,785
750	334	360	2,528
1,000	432	414	3,060
1,650	482	468	3,750
2,500	720	525	5,095

A Brick Chimney described by I. W. Hubbard in the Proceedings of the Engineers' Club of Philadelphia, 1901, was built in 1909 at Camden, N. J., for Mellar & Rittenhouse Co. The chimney is 212 ft. high above the level of its concrete base, which is 7 ft. thick, making a total height of 219 ft. The bottom of the concrete is 19 ft. below the ground level. The concrete base is 34 ft. square and weighs 526 tons. The lower 11 ft. of the chimney is of common brick, stepped up in 2 ft. steps, being 28.5 ft. square at the bottom and 18.5 ft. square at the ground level. This brickwork below the ground level weighs 360 tons. Above the ground level, to a height of 22 ft., red brick were used. Above this the chimney takes its circular form and is made of perforated

radial bricks manufactured by the Alphons Custodis Chimney Construction Co., of New York City. The inside diameter of the chimney is 11 ft. at the bottom and 8.5 ft. at the top. The thickness of the shell of perforated radial brick decreases from 26 ins. to 7 ins.

The materials for construction were raised in buckets by a hoisting-engine. The work was done from the inside from platforms erected as the work progressed, the platform also supporting the tripod holding the pulley-wheel through which the hoisting cable ran.

The total weight of the stack is 1,640 tons (including the 360 tons of concrete) on a ground area of 1,156 sq. ft., or 1.42 tons per sq. ft.

The cost was $12,250 and the chimney was designed for 2,000 h.p., making a unit cost of $6.12 per horsepower.

One of the Highest Chimneys in the world, described in Engineering News, Sept. 1, 1898, was built in 1892 for the Omaha and Grand Smelter, Denver, Colo., at a cost of $53,000. Its dimensions are:

Height above stone table at ground, ft.	352.5
Size at base, which is square, ft.	33 by 33
" " throat, diameter, ft.	20
Thickness of outer shell at base, ins.	48.5
" " " " " top, ins.	13
" " inner " " base, ins.	26
" " " " " top, ins.	9
Diameter of flue, ft.	16
Foundation, square, ft.	56 by 56

The foundation is 16 ft. thick, the lower 8 ft. being concrete, and the upper 8 ft. being brick.

The outer part of the chimney is rectangular up to 64 ft. in height, above which it is octagonal. The weight of the stack above the foundation is 12,376,500 lbs. The materials in the chimney are as follows:

Brick	1,943,000
Lime, bushels	8,480
Cement in brickwork, bbls.	707
" " concrete "	775
" " stone work "	26
Sand, cu. yds.	2,331
Railroad iron in concrete base, lbs.	48,960
Steel beams under openings, lbs.	2,574
Wrought-iron bands and rollers, lbs.	23,180
Cast-iron cap, lbs.	22,000
Cast-iron plates, lbs.	36,474

The chimney was built in 120 days.

In 1905 a chimney 350 ft. high above the ground was built by the same company for Heller & Merz Co., Newark, N. J. The chimney is designed to handle acid gases having a temperature of 1,500 degs. F., and is lined with fire and acid proof brick 4 ins. thick. The shell of the chimney is made of perforated radial bricks. The foundation consists of 324 piles supporting a con-

crete base 45 ft. square at the bottom, 30 ft. across at the top (the top being hexagonal) and 14 ft. thick. The brick shaft of the chimney rises 340 ft. above the top of this concrete base. The concrete base contains 766 cu. yds., which required 800 cu. yds. of stone, 400 cu. yds. of sand and 1,000 bbls. of Atlas cement. The stack required 2,000 tons of brick, 500 bbls. cement, 800 bbls. lime, 600 cu. yds. sand. The inside diameter is 8 ft. at the top, and the shell is 11.13 ins. thick (including the 4-in. lining) at the top. The outside diameter is 27.5 ft. at the bottom, and the shell is 42 ins. thick (including the 4-in. lining) at the bottom. The acid proof lining is supported on corbels projecting from the main shell, at 20-ft. intervals.

The contract price for the stack and foundations was $32,000 and the time required for the work was 7 months.

Chimneys for Acid Gases. In 1901 a very high chimney described in Engineering News, Nov. 21, 1901, was built by the Alphons Custodis Chimney Construction Co., of New York, for the Orford Copper Co., Bayonne, N. J. The chimney is designed to carry acid gases. The height of the stack is 365 ft. above the ground level. Below the ground level is a concrete foundation 15 ft. thick, 45 ft. square at the base and 34 ft. square at the top, containing 1,980 tons of concrete. This base rests on 360 piles, the ground being marshy. The weight of the brick stack is 2,528 tons, making a total of 4,508 tons on the pile foundation. Excepting the lower 30 ft. of the stack, which is common red brick, the shell of the stack is of perforated radial brick. The stack has an inside diameter of 10 ft. at the top and 20 ft. at the bottom. The shell is 10.5 ins. thick at the top and 46 ins. at the bottom. The lower 64 ft. are lined with acid proof brick. This chimney and its foundation cost $50,000.

Cost of Demolishing a Brick Chimney with Dynamite. W. J. Douglas (Engineering News, Dec. 4, 1902) gives the following cost of demolishing a brick chimney:

The chimney was built of hard burnt red brick laid in natural cement mortar, in the proportion of about one cement to three sand, and was lined with fire brick also laid in natural cement mortar. An air space separated the chimney proper from the lining. Portland cement mortar was used for a few feet above the foundation, and spasmodically throughout the stack, but was used too infrequently to be of value. The height of the chimney above the foundation was 150 ft. The diameter of the opening at the base was 7 ft., that at the top was also 7 ft. The bottom of the stack was 15 ft. square, up to a point 33 ft. above the foundation, where it changed to an octagon. The thickness of the outer wall at the base was 34 ins.; the thickness of the outer wall at the top, 13 ins.; and the thickness of the inner circular lining wall at the base, 13 ins. The inside lining stopped at a point 100 ft. above the foundation terminating in a 4.5-in. wall. Fifty feet of the chimney were removed by pick and bar before resorting to dynamite, thus reducing the height of the stack to 100 ft. This was done on account of the feeling prevalent among

the surrounding property-owners that their buildings would be endangered by throwing down the stack in its entirety.

After the stack had been reduced to 100 ft. a test blast hole was drilled into the northwest corner of the stack about 3 ft. above the foundation, on a level, and on an angle of about 45 degs. with the north face. This hole was loaded with one dynamite cartridge (all dynamite was 40% Star brand), and fired without even cracking the wall. A second hole similarly located, and just 1 ft. above the first one, was then drilled and loaded with five sticks or cartridges and fired, loosening about one-third of a cubic yard of brick, which was easily barred out. Then shots of two and three sticks were made until all of the north wall for a height of 3 ft. had been removed excepting about 5 ft. at the east end. In the east wall of the stack there was a furnace opening 6 ft. wide, so that by the excavation of the north wall just described there now remained only a pillar 5 ft. long and 34 ins. thick carrying a large portion of the weight of the east

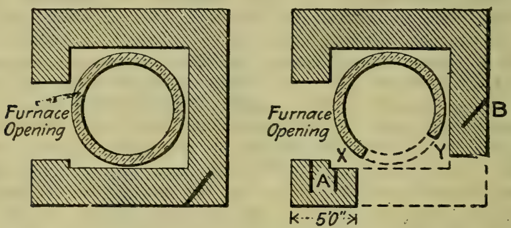


Fig. 4. Diagrams showing arrangement of dynamite blasts for demolition of 150-ft. chimney.

and north walls. Then about 5 ft. of the fire brick lining was barred out for a height of 1 ft.

The chimney was now in shape to be blasted down. Two holes were drilled into the 5-ft. pillar from the back on a dip of 45 degs., with the horizontal, and each hole was loaded with six sticks of dynamite. Then a hole was drilled into the west face at B, on a dip of 10 degs. and on an angle of 45 degs. with the west face and about 5 ft. from its end. Five sticks of dynamite were placed at X and five sticks at Y, in order to tear out the lining. This was not thought essential, but its use probably allowed the stack to fall further from the base, giving the contractor a better chance to handle the material in the demolished structure. These sticks at X and Y were laid between the outer and inner walls and covered with clay. Two exploders were placed in each hole in order to make sure of the blast and the 25 sticks located as described were fired at one time by a battery. Before blasting the chimney was carefully planked on the east, north and west faces; 2-in. and 3-in. by 12-in. by 16-ft. planks were used. Single planking was used on the west face, and double planking was used on the north and east sides. At the northeast corner and

for 5 ft. on either side 6-in. by 12-in. by 12-ft. timbers were used instead of one of the thicknesses of planking. When the charge was fired the planking was found sufficient to keep the debris, resulting directly from the blast, from flying over 100 ft. from the chimney.

After the blast the stack immediately toppled over toward the north. The motion was slow and steady until a point about 20 degs. from the vertical was reached, in which position it sheared into three sections and fell rapidly to the ground. About 60.000 bricks were completely separated from each other by the jar; these bricks were almost free of mortar. The mortar was not much stronger than first-class lime mortar. The area which

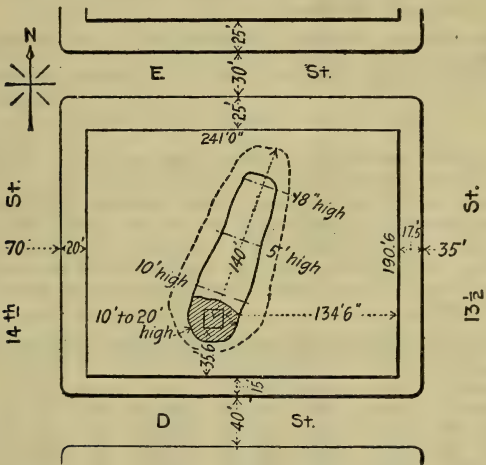


Fig. 5. Sketch plan showing areas covered by debris and scattered bricks.

was covered by the stack after the fall is shown by the irregular heavy full-lines. The outside dotted irregular line shows the limit outside of which no bricks were thrown. The area between the full line and the dotted one, aforementioned, was partially covered with scattered brick.

All brick excepting those included within the cross-hatched area were loose and practically free of mortar. The bricks in this area were in masonry blocks varying in size between 2 by 2 by 2 ft. and 3 by 6 by 12 ft., and averaging 3 by 3 by 6 ft. The bricks in these blocks were separated from each other by means of wedges and picks. The use of dynamite for this work was thought both dangerous and uneconomical on account of the damage to the individual bricks. The bricks were readily removed

by means of wedges. Old whole bricks are at present worth, exclusive of haul, about $4.50 per thousand, and bats are worth about 40 cts. per cu. yd. It is thought that the stack was demolished with a profit to the contractor. The following is an approximate cost of the work:

Removing first 50 ft. with pick and bar	$150.00
Dynamiting stack	60.00
Cleaning new brick, 116,000 at 60 cts.	69.60
	$279.60
Incidentals, 25%	69.90
Total	$349.50

On the credit side we have:

118,000 whole brick removed, estimated to be worth when cleaned	$531
About 240 cu. yds. old brick sold, worth it is thought at about 40 cts. per cu. yd.	96
Total	$627

The estimated number of bricks in the stack was 140,000 red brick and 14,000 fire brick. These are accounted for, as follows: 116,000 whole red bricks removed; 2,000 whole fire brick removed; 24,000 bats removed; 12,000 bricks not of any use; total, 154,000.

Weight per Foot of Sheet Steel Chimneys. C. D. Wesselhoeff (Data, May, 1915) states that the cost of sheet steel chimneys varies from 3.5 to 6.5 cts. per lb., the higher value being for the shorter chimneys.

TABLE VI. WEIGHTS OF SHEET STEEL CHIMNEYS

Diam., in.	Thickness, w. g.	Lbs., per ft.	Diam., in.	Thickness, w. g.	Lbs., per ft.	Diam., in.	Thickness, w. g.	Lbs., per ft.
10	No. 16	7.20	26	No. 16	17.50	20	No. 14	18.33
12	No. 16	8.66	28	No. 16	18.75	22	No. 14	20.00
14	No. 16	9.58	30	No. 16	20.00	24	No. 14	21.66
16	No. 16	11.68	10	No. 14	9.40	26	No. 14	23.33
20	No. 16	13.75	12	No. 14	11.11	28	No. 14	25.00
22	No. 16	15.00	14	No. 14	13.69	30	No. 14	26.66
24	No. 16	16.25	16	No. 14	15.00	..	......	....

Cost of Steel Chimneys. J. H. Boughton gives the cost of steel chimneys shown in Table VII.

TABLE VII. COST OF STEEL CHIMNEYS

H.-p.	Height, ft.	Diameter, ins.	No. of iron	Price of chimney complete
25	40	16	12 and 14	$60
..	40	18	12 and 14	70
..	50	18	12 and 14	85
75	50	20	12 and 14	90
..	50	26	12 and 14	105
..	60	22	12 and 14	110
100	60	24	12 and 14	125
..	60	26	12 and 14	135
..	60	28	12 and 14	150

H.-p.	Height, ft.	Diameter, ins.	No. of iron	Price of chimney complete
125	60	28	10 and 12	190
..	60	32	10 and 12	205
150	60	34	12 and 14	165
200	60	36	10 and 12	215
225	60	38	10 and 12	230
250	60	42	10 and 12	260
300	60	46	10 and 12	290
400	60	52	10 and 12	340

Dimensions of Steel Chimney Foundations. Table VIII was compiled by Kidder from data supplied by the Philadelphia Engineering Works.

TABLE VIII. SIZES OF FOUNDATIONS FOR SELF-SUSTAINING STEEL CHIMNEYS, HALF LINED

Clear diameter, in ft.	3	4	5	6	7	9	11
Height in ft.	100	100	150	150	150	175	225
Least diameter of foundation in ft.	15.75	15.25	20.33	21.83	22.58	25.75	29.92
Least depth of foundation in ft.	6.5	7.0	9.0	8.0	9.0	10.0	13.0
Height in ft.	....	125	200	200	250	275	300
Least diameter of foundation in ft.	....	17.5	23.66	25.0	29.66	33.5	36.0
Least depth of foundation in ft.	....	7.5	10.0	10.0	12.0	12.0	14.0

Cost of Steel Stack and Breeching. Following was the cost of a stack and breeching, 80 ft. high, 5 ft. diameter of No. 8 steel. The breeching was 14 ft. by 4 ins. by 5 ft. of No. 10 steel.

Cost installed	$741.68
Cost per foot height	9.27

A Self-Supporting Steel Stack described in Engineering News, Jan. 28, 1897, was built in 1896 for the Ridgewood pumping station of the Brooklyn Water Works, by the Philadelphia Engineering Works, for $10,000. It is 217 ft. high above the foundation and 8 ft. inside diameter at the top. The thickness of the steel plates is as follows:

Height, ft.	Thickness, ins.
0 to 40	½
40 to 80	7/16
80 to 120	⅜
120 to 160	5/16
160 to 217	¼

At a height of 40 ft. the outside diameter is 11 ft., and 15 ft. lower down the stack starts to flare out, its outside diameter being 24 ft. at the base. It is lined with red brick to a height of 95 ft., the thickness of the lining being 13 ins. for the lower 25 ft. and 9 ins. above that. Below the ground level, the chimney

is entirely of brick for a depth of 18.5 ft., resting on a concrete base 4.5 ft. thick and 30 ft. in diameter, octagonal in shape.

Cost and Size of Wedge Rope Sockets are particularly useful in connection with guy ropes of all types and safety cables where small adjustments in length are desirable. These sockets can be used either with U-bolts or eye-bolts, as illustrated in Fig. 6, and a considerable range of adjustment can be secured.

Size of rope, ins.	¾	1	1¼	1½–1⅝	2
Rough dia. of holes, R. ins.	1⅜	1⅝	2	2½	3
List price socket and wedge only	$3.95	$6.10	$7.85	$14.30	$25.70
Diameter A, ins.	1⅛	1⅜	1¾	2¼	2¾
Distance threaded, C. ins.	9½	11½	14¼	17½	21
Length U-bolt, D. ins.	15	18½	22½	27	35
List price U-bolt and 2 nuts	$2.30	$3.45	$5.85	$11.75	$21.50
Length eye bolt, E. ins.	21½	26½	32	39½	51
Opening, G. ins.	1½	2	2½	3	3½
Size hole, J. ins.	1⅞	2⅛	2⅝	3⅛	4⅛
List price 1 eye bolt and nut	$4.30	$6.10	$7.85	$19.30	$27.90

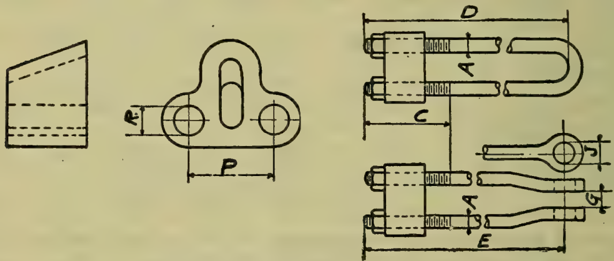


Fig. 6. Wedge rope sockets.

Cost of Removing and Replacing Top of a Steel Stack. A steel smoke stack described by C. J. Carew (Engineering and Contracting, May 1, 1907), which was 100 ft. high, had become so corroded that it was necessary to replace the top 56 ft. with new steel. Owing to the location a new stack could not be built on the ground and up-ended in the usual manner. Moreover, the old stack had to be taken down piecemeal and the work had to be done, if possible, without shutting down the plant. A Sunday was selected for the work, which was conducted as follows, the plan being to cut away and lower the old stack in sections and to hoist and bolt up the new stack in similar sections:

A timber tower was built enclosing the stack, as shown in the accompanying sketch. This tower had four legs or corner struts of triangular trough sections made up of two 2 by 8-in. planks, while the bracing was 1 by 6-in. boards. It was 11.5 by 23 ft. in plan at the bottom and 1.5 by 15 ft. at the top. The mode of guying is indicated in the drawing. As will be seen, the old stack occupied one-half the interior space of the tower, the other half being used for hoisting and lowering the steel sections. The hoisting apparatus consisted of a trolley running on an I-beam

laid across the top of the tower. This trolley was operated by a rope passing down the stack and to a drum operated by a pneumatic motor.

To remove the old stack three holes were first punched through the shell near the top to receive the hooks on three short chains hung from a ring suspended from the hoisting tackle. Then a section about 14 ft. long was cut off with cold chisels and lowered. The cutting was quickly done, owing to the corroded condition of the steel. Once free a section could be lowered in about three minutes. Then a second section was removed in the same way, and so on until the portion of the old stack to be left standing was reached. The manufacturers of the new stack then riveted an angle iron ring to the top edge and the job was ready for the work of erecting the sections of new stack.

The length of new stack added was 56 ft., in five sections, four 12 ft. long each, and one 8 ft. long; the lower 30 ft. was 3/16-in. steel and the upper 26 ft. was 1/8-in. steel. The heaviest sections weighed 1,880 lbs., and the total weight of new steel was 7,500 lbs. This included the rings of 2 by 2-in. angle at the ends to form flanges for bolting the sections together. The sections were hoisted and bolted up one at a time.

So much for the method. The time occupied and the labor costs were as follows: The whole work of erecting the tower, taking down the old stack, erecting the new stack and taking down the tower was done by four men, one of whom had taken the job on contract for $110. The usual wages of these men were: For the contractor, $2.75 per day; for one man, $2.50 per day, and for the other two men, $2 per day each. On this basis of wages we can figure the cost as follows:

Erecting tower, adjusting tackle, putting up I-beams and trolleys and connecting air motor to windlass:

Contractor, 26 hours at 27.5 cts.	$ 7.15
1 man 26 hours at 25 cts.	6.50
2 men 26 hours at 20 cts.	10.40
Total labor	$24.05

There were 3,000 ft. b. m. of timber, making the labor cost of erection practically $8 per M. ft. b. m. It was really somewhat less than this, as the total of $24.05 given above includes some other work, as indicated.

Taking down old stack:

Contractor, 3½ hours at 27.5 cts.	$0.926
1 man 3½ hours at 25 cts.	0.875
2 men 3½ hours at 20 cts.	0.700
Total labor	$2.537

The weight of steel removed is not obtainable, but assuming that it was half the weight of the new steel which took its place, we have 3,750 lbs. = 1.875 tons of steel removed at a cost of $1.41 per ton.

Laying out, punching and bolting first angle iron to old portion of stack:

2 men 2½ hours at 50 cts.	$2.50

This work was done by the manufacturer of the new stack and its cost was included in his contract. The item is actual, but the rate of wages has been assumed.

Erecting new stack:

Contractor, 4 hours at 27.5 cts.	$1.10
1 man 4 hours at 25 cts.	1.00
2 men 4 hours at 20 cts.	1.60
Total labor	$3.70

The weight of the new steel stack was 7,500 lbs. or 3.75 tons, so that the cost of erection was just short of $1 per ton of steel.

Removing tower, adjusting guys, painting stack and cleaning up:

Contractor, 19 hours at 27.5 cts.	$5.22
1 man 19 hours at 25 cts.	4.75
2 men 19 hours at 20 cts.	7.60
Total labor	$17.57

Charging this whole amount to the work of removing the tower we have a cost of $5.86 per M. ft. b. m.

We can now summarize the labor cost of the work as follows:

Erecting tower and hoisting plant	$24.05
Taking down old stack	2.54
Building angle to old stack	2.50
Erecting new stack	3.70
Removing tower, etc.	17.57
Total cost	$50.36

The 3,000 ft. b. m. of lumber in the tower was made up as follows:

1,400 ft. B. M. chestnut at $20 for legs	$28.00
1,600 ft. B. M. hemlock at $19 for bracing	30.40
Total lumber	$58.40

Not more than 5 per cent. of the lumber was destroyed and the remaining 95 per cent. was finally used for other purposes for which it had been originally purchased.

The Tallest Steel Chimney. Fig. 8 shows a steel chimney erected at the United Verde Copper Works in Arizona, described in Engineering and Contracting, June 27, 1916, and named by A. G. McGregor in Transactions American Institute of Mining Engineers in August, 1916, the tallest steel chimney ever built. Specifically this chimney is 30 ft. 9.5 ins. in diam. and 400 ft. 1 in. high. The drawings present all the essential structural features and may be read for details.

Cost of Erecting a 160-Ft. Steel Stack. An exceedingly interesting job of hoisting engineering is described in Engineering and Contracting, Nov. 10, 1909. The job consisted in erecting a steel stack 66 ins. by 160 ft. in size in one piece, after it had been assembled on the ground, with an erecting plant consisting of a

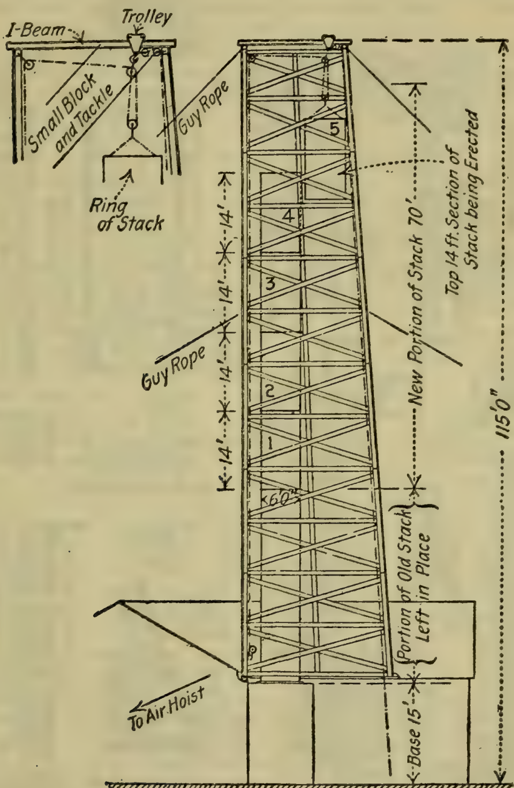


Fig. 7. Method of rebuilding a steel chimney.

72-ft. mast and a 7 by 10-in. Lidgerwood hoisting engine with the necessary tackle.

The stack was built of ¼-in. steel for 85 ft. from the base and of ⅛-in. steel for the top 75 ft.; ⅜-in. rivets were used. The stack came to the ground in four 40-ft. sections. These were laid in line, with the base of the bottom section as close as practicable to the foundation, and riveted together on the ground.

After being riveted and lined out the stack was braced or reinforced inside to prevent buckling and crushing of the plates at the slings. The bracing consisted of cross frames of 4 by 6-in. timbers placed inside the shell and spaced every 5 ft., beginning

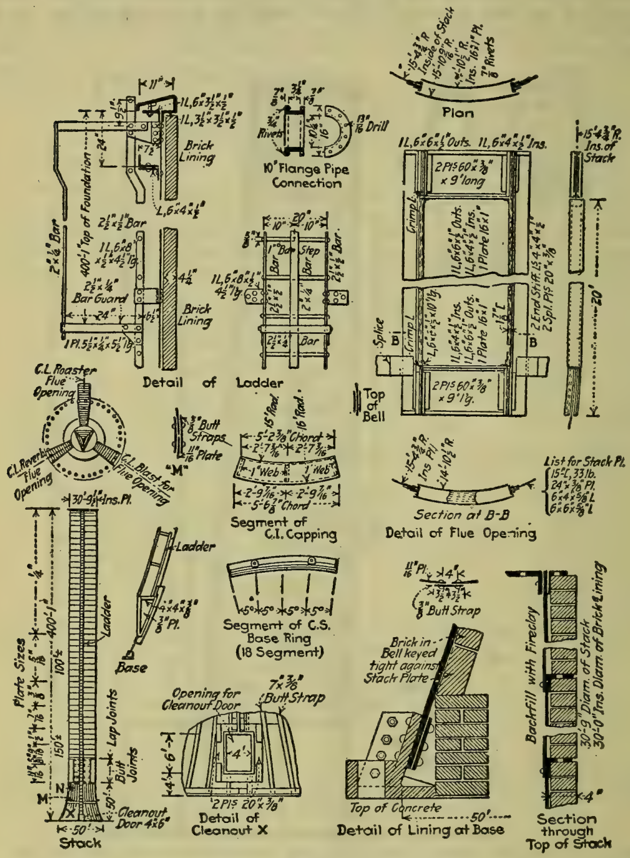


Fig. 8. Details of tallest steel chimney.

at a point 20 ft. from the top. These frames were wedged into the shell tight enough to hold firmly and yet not bulge the plates or seams.

The next step was to place the hoisting plant. A 72-ft. mast was erected on top of the boiler house 20 ft. above ground, so

that its total height was 92 ft. The mast guys consisted of five 1⅛-in. galvanized wire ropes radiating from the spider casting at the top of the mast. In addition a sixth guy was attached to the mast 20 ft. below the top and carried back directly in line with the stack. This guy was designed to prevent the mast from buckling under the pull, which failure, if it occurred at all, was figured would occur at the point mentioned; that is, about 20 ft. below the top. The mast was a 12 by 12-in. timber. At the top of the mast there was fastened a triple block shackled to the top casting and also lashed by a wire cable passing four times around the mast and securely clamped. The hoisting engine, a 7 by 10-in. Lidgerwood, was set 25 ft. to one side of the stack and 125 ft. from the base.

The line used was 1,400 ft. of ¾-in. crucible steel rope spliced at one point with an 18-ft. splice. This line was rigidly inspected before it was run through the blocks. It was carried from the engine to and through the foot block casting sheave; thence up the mast to the top sheave; thence down to a single block lashed to the stack 30 ft. from its top; thence up to the middle sheave in the triple block lashed to the mast head; thence down to a second single block lashed to the stack 55 ft. from the top; thence up to the right-hand outside sheave of the triple block; thence down to a third single block lashed to the stack 80 ft. from the top; thence up to the left-hand outside sheave of the triple block, and the free end, thence to another in the ground about 60 or 65 ft. from the base of the stack.

The single blocks were lashed to the stack by several turns of wire rope passing around the shell and 6 by 6-in. timbers laid along it on the under side. These timbers acted both as longitudinal stiffeners and as spacers to keep the lashings from sliding up or down the shell. To prevent possible cutting of the line the thimbles were all removed from the shell of the triple block and the lines were kept clear by running them through the middle sheave, then to the right and to the left as described above.

With everything ready as described hoisting was begun at 1:30 p. m. and at 5 p. m. the stack was in place with all guys fastened. The first lift made was 75 ft. Then hoisting was stopped until the permanent guys, 24 in all, each a ½-in. wire cable, were fastened to the stack attachments. Lifting was then resumed and continued until the stack stood only about 15 degs. out of plumb. Hoisting was then stopped and the guys secured to their ground anchors. The stack was then raised plumb, jacked over the stud bolts on the foundation and the guys permanently clamped.

The cost of the work described was not kept in such a way that it can be itemized, but the total cost including riveting, erecting mast on the boiler house, raising, buying 4 pairs of cone clamps for the guys and 4 sets of ¾-in. blocks for hauling in guys, and bracing the stack inside was $250. A gang of 8 men at $1.30 per day and one top man at $2.25 per day were employed, with some extra men for about 2 hours.

The erection as described was planned and carried out by

George B. Nicholson, a hoisting engineer. Incidentally it may be stated that Mr. Nicholson undertook the job after it had been rejected as impossible by expert riggers. We consider this a rather remarkable job of hoisting engineering. Only one man, Mr. Nicholson, was a skilled man, all the others being ordinary laborers with no experience in hoisting and rigging. In addition the method of rigging the tackle, using only one line to run through three sets of blocks on the stack and one block on the mast, is notable. We are indebted for the information from which this description has been prepared to F. W. Raymond.

CHAPTER V

MOVING AND INSTALLING

To aid in estimating the cost of hauling and installing machinery many specific data have been collected and grouped in this chapter. Where costs of moving and installing were combined with other functional costs in such manner that they could not be separated without injuring the value of the data they have been included in other chapters. The index and list of chapters will aid the reader in locating other costs of moving and installing.

Cost of Loading and Unloading Machinery. Table I is from a recent appraisal (prior to the war).

TABLE I. COST OF LOADING AND UNLOADING MACHINERY

Weight of piece, tons	Cost without crane, per ton	Cost with crane at ry. station only, per ton	Cost with crane at power station only, per ton	Cost with crane at both ends, per ton
1	$11.50	$8.12	$3.45	$0.80
2	7.50	5.03	2.25	.53
3	6.33	4.50	1.90	.44
4	5.70	4.12	1.77	.44
5	5.90	4.15	1.75	.41
6	6.01	4.32	1.85	.48
7	6.45	4.50	1.93	.45
8	7.00	4.93	2.10	.49
9	7.45	5.17	2.23	.52
10	8.00	5.60	2.40	.56
11	8.45	5.95	2.57	.58
12	8.75	6.25	2.75	.63

For large generators and motors assume total shipping weight, divided as follows: Revolving part, 51%; upper part, 24%; lower part, 25%.

For motor generator sets assume total shipping weights divided equally between motor and generator, and apply same ratio for parts.

Cost of Hauling One Piece Loads. The data in Table II are from a recent appraisal (prior to the war).

Where the haul is over 20 miles on mountain roads, use average condition cost.

For large generators and motors assume total shipping weights divided as follows: Revolving part, 51%; upper part, 24%; lower part, 25%.

For motor generator sets assume total shipping weights divided equally between motor and generator, and apply same ratio for parts.

TABLE II. COST OF HAULING ONE PIECE LOADS

Weight of pieces, in tons	Flat country good roads, cost per ton-mile	Average conditions, rolling country, cost per ton-mile	Mountain roads, cost per ton-mile
1	$0.40	$0.45	$0.50
2	.35	.37	.40
3	.35	.40	.46
4	.36	.47	.57
5	.38	.55	.70
6	.40	.62	.62
7	.42	.68	.93
8	.44	.74	1.04
9	.46	.80	1.13
10	.48	.86	1.24
11	.49	.90	1.31
12	.50	.93	1.34
13	.52	.95	1.38
14	.54	.98	1.42
15	.55	1.00	1.54
16	.56	1.02	1.47
17	.58	1.04	1.50
18	.60	1.06	1.52
19	.61	1.07	1.53
20	.64	1.09	1.55

Hauling small miscellaneous material, including loading and unloading per ton-mile. Cost as follows:

	Per ton-mile
Flat country good roads	$0.60
Rolling country average conditions	.90
Mountain roads	1.20

Effect of Grades on Cost of Hauling. H. T. Curran (Engineering and Contracting, Oct. 6, 1915) states that unloading and hauling depend upon local conditions. There will be a fixed average charge of from 30 to 40 cts. per ton. Small pieces should be handled for less, but large, unyielding pieces, such as a tube mill, can easily cost up to $1 per ton. Probably 75 cts. per ton-mile would be a good average for hauling on any kind of a decent road and grade. By consulting local freighters these things can be definitely settled. The curve, Fig. 1, shows the variable cost of hauling on different grades.

Truck-Drawn Pole Trailers. In comparing the expenses of using horse and auto trucks to transport poles Electrical World, May 26, 1917, states that the Springfield district of the New England Telephone & Telegraph Company found that the truck-drawn trailer will do the same work as a horse-drawn trailer in about one-sixth of the time. During 115 hrs. of pole hauling in 12 days the truck traveled 441 miles at a cost of little more than 25 cts. per mile. Using horses for the same work would have required 71 days at a rate of 97 cts. per mile. An additional point in favor of such trucks is the fact that the hired teams are slow in delivering poles, causing a great deal of lost time and often neces-

sitating an additional light team to transport the men and tools. When using a truck and trailer, the men, poles and tools will arrive on the job at the same time, so the work can proceed without delay.

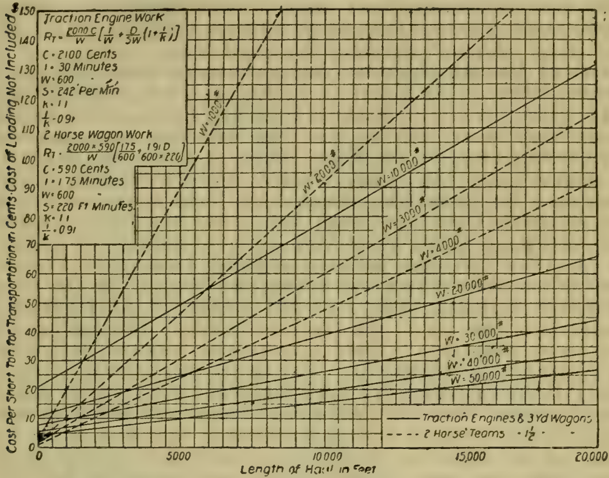


Fig. 1. Cost per ton comparison curves between train- and team-drawn dump wagons.

Cost of Hauling Poles and Cross-Arms. The following are the costs of hauling material for a light and power plant.

Character of country	Poles per ton-mile	Cross-arms per ton-mile
Mountain roads	$1.00	$1.20
Rolling or swampy	.75	.90
Flat, good roads	.50	.60

Cost of Mule-Back Transportation of Machinery in Mexico. F. C. Roberts and W. C. Bradley (Engineering News, Aug. 12, 1912) give the following cost of transporting sectionalized machinery for a smelter in Mexico. The loads carried varied from 350 lbs. to 680 lbs. per mule.

The freight rate for an ordinary *carga* of two pieces, weighing 304 lbs., from Durango to Ventanas, a distance of 105 miles, fluctuates between $4.25 and $6 per carga, or between $29.25 or $42 per metric ton, an approximate average cost of $32.80 per short ton; while, for individual pieces weighing up to 425 lbs., that is, *cuarteos*, a special charge of from $10 to $100 is made. The railroad rate from any center in the United States to Durango is

$1.60 per 100 lbs., or $32 per short ton. Add to this the local expenses for discharging, transferring, re-packing, etc. (another $2 per ton), and the total of $66 per ton is reached, besides the duties.

About 2,500 tons of material (1,500 tons of machinery, and 1,000 tons of supplies and stores) were transported during a period of 16 months. It made 17,500 mule-loads, or 262,500 mule-load days, taking 15 days for the round trip.

Cost of Hauling Machinery for a Pumping Plant. W. L. DeMoulin (Proceedings American Society of Civil Engineers, June, 1915) gives the cost of hauling machinery over a rough mountain wagon road, more than 6 miles long, extending from Morenci to the pumping plant on the Eagle River. A great part of the road is blasted along the rocky hillsides. Out of Morenci, the road runs up a hill requiring a climb 3,400 ft. in length, with grades varying from 17 to more than 36%. Near the plant, there is a continual down grade along very rocky hillsides, with grades of 25 to 40%. On steep grades, snubbing posts were placed at regular intervals, during the construction period, for the purpose of letting the heavy loads down hill gradually. All material was hauled from Morenci to the plant on wagons. The average loads are about 3,000 lbs. A load of this size requires 10 horses to make the hill out of Morenci. During the construction period, the heavy pieces of machinery were taken out on a wagon built for heavy hauling, with 4-in. iron axles. Extra rear and front wheels were carried along to replace immediately any that broke down. Some of the pieces of machinery weighed from 15,000 to more than 24,000 lbs. each. Twenty horses could make the hill out of camp with a load of 4 tons, and 24 horses could manage a load of 5 or 6 tons. It was necessary to use a number of triple blocks, with from 6 to 8 horses pulling down hill, in order to work slowly a load heavier than 6 tons up the hill. At the plant, it was necessary to pack material and supplies around by Mexicans and burros, as in many cases the work was prosecuted at points inaccessible by any other method of transferring material. The cost of transferring machinery from the flat cars at Morenci to the plant, placed ready for the erector, averaged about $52.45 per ton, which is about twice what the freight per ton amounted to from Milwaukee to Morenci. The 40-lb. and the 54.74-lb., 10-in. pipes were transferred through a tunnel and distributed by wagon to stock piles. In this way, the haul over the steep hill out of town was avoided. From the stock piles, the pipe was "snaked" by horses to the place where it was being laid. The tunnel was too small to permit passing heavy material through it. The cost of delivering the pipe from the cars to the location of the proposed line was $6.80 per ton. The average cost for each 10-in. pipe line laid complete, was $2.20 per ft. The average labor charge, for laying the lines by contract, was 28 cts. per ft. for each 10-in. pipe line.

Costs of Installing Electrical Apparatus and Methods of Computing Profits in Contracting. The following data are taken from

an article by Mr. Louis W. Moxey, Jr., Electrical World, Oct. 16, 1915:

There are two items which combined compose the cost of conducting an electrical contracting business. The first item includes the cost of materials and labor actually used on jobs, such as engines, dynamos, panelboards, conduit, wire, etc., together with the salaries of the foreman, journeyman, helpers and apprentices. This item may be called, for convenience, shop or raw cost.

The second item includes the cost of materials and labor expended in securing a contract and in the execution of the job. It embraces the salaries of the officers, bookkeeper, stenographer, bill clerk, draftsman, superintendent, etc., and the cost of rent, heat, light, taxes, insurance, stationery, postage, telephone and the like. This item is called manufacturer's expense or overhead charge.

The writer has found it more convenient and logical to compute the manufacturer's or overhead expense as a percentage of the shop cost, instead of as a percentage of the selling price. An estimate of overhead expense should be made at least once or twice a year and the percentages thus obtained added to the shop cost in all estimates made in the succeeding period to obtain the real cost; e. g.

Shop Cost:	
Pay of foremen, journeymen, helpers and apprentices....	$ 80,000
Cost of material, engines, generators, conduit, wire, etc.	200,000
Total shop cost	$280,000
Overhead Expense:	
Salaries of employers, co-partners or officers............	$ 30,000
Salaries of office employees — bookkeepers, clerks, etc....	8,000
Salaries of superintendent, draftsman and engineer.....	10,000
Stationery, telephones, taxes, insurance, rent, etc........	8,000
Total manufacturer's expense	$ 56,000

Manufacturer's or overhead expense as a percentage of shop cost equals $56,000 ÷ $280,000, or 20%.

The real cost, therefore, of the year's business would be the shop cost, $280,000, plus the overhead expense of $56,000, or $336,000. Should the selling value of this work be $369,600, the contractor has made a profit of 10% on the investment made. Should the selling value, however, be only $334,992, he has lost 3% on his investment. A true estimate should, therefore, be made for any job as follows:

Shop cost	$10,000
Overhead expense at 20%	2,000
Real cost	$12,000
Profit at 10 per cent	1,200
Amount of proposal	$13,200

Some contractors figure their overhead expense as a percentage of the selling price. If a contractor's overhead expense is 20%

of his selling price and he desires to make a profit of 10% on the selling price, he would not make it if he used the following method:

Shop cost	$ 1,500
20% overhead expense plus 10% profit	450
Amount of proposal	$ 1,950

To get the results desired — namely, 20% of selling price as overhead expense and 10% of selling price as net profit — the estimate should be made in the following manner: If the shop cost is $1,500, this amount must represent 70% of the selling price, for the overhead expense is taken as 20% of the selling price and the profit is taken as 10% of the selling price. Hence the selling price should be ($1,500 ÷ 70) × 100, or $2,142. The overhead expense is 20% of $2,142 or $428, and the profit is 10% of $2,142 or $214. The sum of these two items, $642, subtracted from the selling price leaves the original shop cost of $1,500. Hence the previous method of estimating was in error by $2,142 — $1,950 or $192.

The entire principle of applying overhead expense and profit as percentages of the selling price is wrong. Profit on a job is actually interest on an investment. The investment in the contractor's business is the sum of the shop cost and the overhead expense. Hence the profit should be computed as a percentage of this sum.

From a collection of data compiled by the National Electrical Contractors' Association on the costs of conducting an electrical contracting business, it appears that the overhead expense of an electrical contractor lies between about 15 and 25% of his shop cost and that the average profit is figured at from 5 to 15% of the gross cost, depending upon the terms of the contract and the nature of the work.

It is not the intention of the writer to present methods for ascertaining approximately the shop cost of labor and materials. No accurate figures for use in estimating the cost of the materials used on a job can be given, owing to the constant changes in price of most of these materials, such as wire, conduit, etc. On the other hand, while the rates paid for labor change, the changes are not of frequent occurrence and tables of labor costs can be worked out on the present rates for labor and any increase or decrease of rates can be taken care of by employing a percentage correction factor.

For engines, generators, motors, transformers, etc., it is always best to secure a bid on the apparatus direct from the manufacturer, especially if a reasonable time be given the contractor to prepare his estimate. It is preferable to have these quotations include the cost of the apparatus delivered and erected in position, as well as the cost of foundation, templets, bolts, painting, etc.

Should, however, the job be a large one and the time for preparing an estimate be short, the approximate cost of the ap-

paratus could be determined if the contractor had prepared curves of cost for the various sizes of such apparatus in the past and had frequently checked them. Such checking is absolutely necessary, as apparatus may vary considerably in price within comparatively short periods of time. Fig. 2 shows how these curves should be prepared.

Separate curves or tables should be prepared for directly connected and belted single- and four-valve or Corliss engines, also

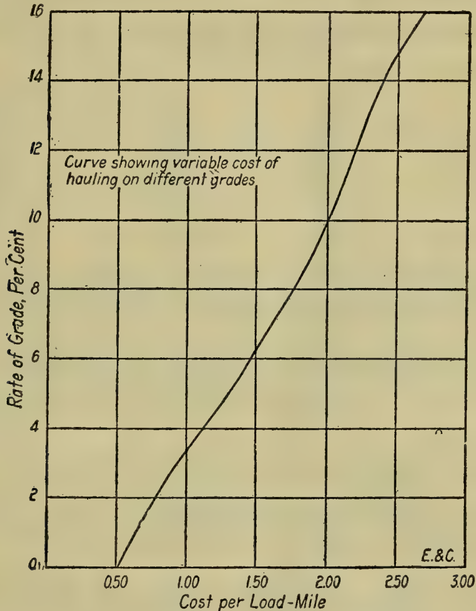


Fig. 2. Curve showing effect of grade on hauling costs in mill construction.

for directly connected and belted direct-current and alternating current generators of various types, as well as for motors of low, medium and high speeds, etc.

The same method could be followed for figuring the cost of certain other kinds of materials, although greater accuracy must be used in plotting some curves, for in some cases price differences of a few cents may be desired. This method can be applied advantageously to such material as panel boxes, panelboards, doors and trim, annunciators, watchmen's clocks, etc.

Tables III to VI are for apparatus delivered and erected ready for the wiring connections of the electrical contractor, and hence

TABLE III. ENGINES AND FOUNDATIONS *

Horsepower Rating	Cost per horsepower		
	Single	Tandem-compound	Four-valve
50 — 100	$16	...	...
100 — 200	15	$26	$25
300 and above	14	24	23

* Installed ready for steam-pipe connections under ordinary conditions. The figures given are based on data from the Ames Iron Works, Oswego, N. Y.

TABLE IV. DIRECTLY CONNECTED D.C. & A.C. GENERATORS *

Rating, kw. d. c.	Cost per kw.	Rating, kva, a. c.	Cost per kva.
25	$25	50	$16
35	23	75	14
50	20	125	13
75	16	135	12
100	15	185	10
125	14	250	9
150	13	312	9
200	12	350	8
250	12	375 and above	8
300 and above	12	...	..

* These prices are based on engine-driven generators installed under ordinary conditions, the sub-bases for the erection of the generators being furnished by the engine contractor. The values are based on data from the G. E. Co.

TABLE V. COST OF SWITCHBOARDS, INCLUDING DYNAMO AND FEEDER PANELS, 220 VOLTS OR LESS *

Rating, kw. d. c.	Cost per kw.	Rating, kva. a. c.	Cost per kva.
25 — 50	$5 — $10	50 — 125	$4 — $6
50 — 100	4 — 8	125 — 350	3 — 4
100 and above	3 — 6	350 and above	2 — 3

* The range of prices is due to variations in the grade of materials and workmanship, the number of instruments, switches, etc. These figures include the switchboards erected complete and ready for the connection of generator cables, power and light feeders, etc. The prices are based on data obtained from the Walker Electric Company, Philadelphia.

TABLE VI. COSTS PER HORSEPOWER OF MOTORS AND NECESSARY RHEOSTATS AND CONTROLLERS ERECTED *

Direct-current		Alternating-current	
Horsepower	Cost	Horsepower	Cost
1 — 3	$50	1 — 1½	$60
5 — 7½	40	1½ — 2	50
7½ — 10	30	2 — 3	40
10 — 15	25	3 — 7½	30
15 — 25	20	7½ — 10	25
25 — 50	18	10 — 20	20
50 — 100	15	20 — 35	18
100 — 250	13	35 — 75	15
250 and above	12	100 and above	13

* Motors are assumed to be of standard speeds, voltage, etc., and to be erected on floor, cost of foundations not being included. The costs include delivery and erection ready for wiring connections and are based on data obtained from the General Electric Company.

are practically the figures the electrical contractor would secure from his sub-contractors.

Tables VII to XII are the complete costs of electrical construc-

TABLE VII. COST OF DYNAMO CONNECTIONS *

Direct-current			Alternating-current		
Rating kw.	Lead sheathed rubber insulation	Rubber-covered cable in conduit	Rating kva.	Lead sheathed rubber insulation	Rubber-covered cable in conduit
25–50	$50–$150	$25–$125	50–125	$100–$300	$ 75–$275
50–100	75–250	50–225	125–350	200–400	175–375
100 and above	100–350	75–325	350 and above	300–500	275–475

* The average flat distance between dynamo and switchboard has been assumed as 25 ft.

TABLE VIII. COSTS OF WIRING AND CONNECTING MOTORS, INCLUDING ALL LABOR AND MATERIAL *

Horsepower	Porcelain	Molding	Conduit
1 — 5	$7.50 — 75	$10 — 100	$15 — 150
5 — 10	30 — 120	40 — 170	60 — 240
15 — 25	75 — 250	90 — 300	150 — 300
25 — 50	100 — 400	125 — 500	200 — 500
50 and over	150 — 500	200 — 600	300 — 600

* The range of figures is due first to structural difficulties, second to the type of motor panel desired, third to the voltage, and fourth to the circuit distance. The lower figures represent the minimum structural difficulties, with fused switches in an iron box and with starting device mounted exposed on wall to side of motor, 220 volt service and 50-ft. to 100-ft. circuit distance. The higher figures represent the maximum structural difficulties, motor panels with circuit breakers, 110 volt service and 150-ft. to 300-ft. circuit distance. The figures do not include the cost of motors, rheostats and regulators.

TABLE IX. AVERAGE COST PER OUTLET FOR WIRING FOR LAMPS IN NEW BUILDINGS *

Outlets	Concealed porcelain	Exposed Wood mldg.	Exposed Metal mldg.	Concealed conduit
Light	$4 — $8	$5 — 10	$8 — 16	$7 — 14
Switch	5 — 10	6 — 12	9 — 18	8 — 16
Wall receptacle	5 — 10	6 — 12	9 — 18	8 — 16
Floor receptacle	7 — 14	8 — 16	11 — 22	10 — 20
Fan	6 — 12	7 — 14	10 — 20	9 — 18
Iron	9 — 18	10 — 20	13 — 26	12 — 24
Electric Heater	7 — 14	8 — 16	11 — 22	10 — 20
Vacuum Control Switch †	12 — 24	13 — 26	16 — 32	15 — 30

* For use where the total cost of the work is about $2,000. For residences the lower figures should be used. For public buildings, such as banks, office buildings, churches and the like, a figure midway between the range of figures given should be used. Where best grade of material and workmanship is required the higher figures should be used. Prices do not include costs of fixtures or appliances, but do include switches and receptacles. For wiring old buildings where porcelain work and conduit work is concealed the figures given should at least be doubled. If porcelain or conduit work is to be installed exposed in either old or new buildings, the figures should be increased at least 25%, the difference of cost depending upon the purpose for which the building is or was designed.

† Includes automatic starter at motor.

tion work, and include all labor and material, and also overhead and profit. A wage rate of 55 cts. per hr. for foremen, 45 cts. per hr. for wiremen, and 25 cts. per hr. for helpers is assumed.

TABLE X. AVERAGE COSTS FOR SIGNAL SYSTEMS RUN CONCEALED IN NEW BUILDINGS *

Bell wiring	Costs per outlet (connected as one outlet) Porcelain	Conduit
Per push-button and bell......	$6	$12
Per drop on annunciator	4	8

* For work on old buildings the figures given above should be doubled. The cost of push-buttons, bells and annunciators is included.

TABLE XI. AVERAGE COSTS OF PRIVATE TELEPHONES

	Porcelain	Conduit
Per desk telephone	$30 — $50	$40 — $60
Per wall telephone......	25 — 45	35 — 55

The average cost per outlet of public telephones in new buildings (concealed work) ranges from $5 to $15 with conduit construction. Cost of wire is not included since the electrical contractor very seldom does the wiring. The range of the figures is due to variations in the distances between outlets. Instruments are assumed to be furnished and installed by the telephone company.

TABLE XII. COST OF MISCELLANEOUS WORK *

Apparatus	Porcelain	Conduit
Time Clocks	$30 — $45	$35 — $50 per clock
Time stamps	65 — 85	70 — 90 per stamp
Fire alarms	20 — 30	25 — 35 per alarm
Watchmen's stations	25 — 35	30 — 40 per station

* The range of the figures given above is due to differences in the grades of workmanship and materials. For old buildings the figures given should be increased from 25 to 50%. These figures include the cost of apparatus as well as the cost of all conductors, conduits and labor.

TABLE XIII. COST OF INSTALLING ROTATING ELECTRICAL MACHINERY

Weight, lbs.	Cost per piece	Weight, lbs.	Cost per piece	Weight, lbs.	Cost per piece
1 to 500	$1 to $5	1,350	$10.35	2,900	$12.45
550	5.45	1,400	10.40	3,000	12.50
600	5.95	1,450	10.45	3,500	12.60
650	6.35	1,500	10.50	4,000	12.70
700	6.85	1,600	10.70	4,500	12.80
750	7.20	1,700	10.90	5,000	12.90
800	7.60	1,800	11.15	6,000	13.00
850	8.00	1,900	11.40	7,000	14.00
900	8.30	2,000	11.50	8,000	15.00
950	8.65	2,100	11.55	9,000	16.00
1,000	9.00	2,200	11.65	10,000	16.25
1,050	9.25	2,300	11.75	....	....
1,100	9.45	2,400	12.00	....	....
1,150	9.65	2,500	12.10	....	....
1,200	9.85	2,600	12.20	....	....
1,250	10.10	2,700	12.30	....	....
1,300	10.30	2,800	12.35	....	....

Cost of Installation of Rotating Electrical Machinery. Table XIII is from a recent appraisal (prior to the war).

All rotating machinery weighing over 10,000 lbs. is estimated at $0.1625 per 100 lbs. The cost includes the cost of setting, grouting or securing, drying and connecting. Unloading costs included with hauling charges, allow for placing apparatus approximately in position.

Costs of Installing Transformers, Rectifiers, etc., of Less Than 75 kw. Capacity as taken from a recent appraisal were the same as for rotating electrical machinery given above and include setting, securing, drying and connecting. The cost of setting the apparatus approximately in position is included in hauling cost, a separate item.

Cost of Installation and Factory Inspection of Power Transformers,— 75 k. w. and Over. The following installation cost from a recent appraisal includes assembling, drying, filling, connecting and starting.

TABLE XIV. COST OF INSTALLATION AND INSPECTION OF TRANSFORMERS OF OVER 75 K. W. CAPACITY

K. w.	Labor 11,000 volts or less	Labor Over 11,000 volts	Material Factory inspection
75	$13.85	$17.85	$10
100	15.35	19.75	10
150	16.60	21.50	10
200	17.85	23.25	10
250	19.10	25.05	10
300	20.35	26.75	10
333	21.60	28.45	10
500	22.85	30.20	10
666	24.10	31.90	10
750	25.10	33.40	10
1,000	26.35	35.10	12.50
1,250	27.60	36.80	12.50
1,500	28.85	38.40	15
1,600	30.10	40.10	15
2,000	31.35	41.75	..

Cost of Installation of Power Transformers, 75 kw. and Over. The following is from a recent appraisal.

TABLE XV. COST OF INSTALLATION OF TRANSFORMERS OF OVER 75 K. W. CAPACITY

K. w.	11,000 volts or less			Over 11,000 volts	
	Cost A	Cost B	Total	Add Cost C	Total
75	$ 9.00	$4.85	$13.85	$4.00	$17.85
100	10.50	4.85	15.35	4.40	19.75
150	11.75	4.85	16.60	4.90	21.50
200	13.00	4.85	17.85	5.40	23.25
250	14.25	4.85	19.10	5.95	25.05
300	15.50	4.85	20.35	6.40	26.75
333	16.75	4.85	21.60	6.85	28.45
500	18.00	4.85	22.85	7.35	30.20
666	19.25	4.85	24.10	7.80	31.90
750	20.25	4.85	25.10	8.30	33.40

	11,000 volts or less			Over 11,000 volts	
K. w.	Cost A	Cost B	Total	Add Cost C	Total
1,000	21.50	4.85	26.35	8.75	35.10
1,250	22.75	4.85	27.60	9.20	36.80
1,500	24.00	4.85	28.85	9.60	38.45
1,600	25.25	4.85	30.10	10.00	40.10
2,000	26.50	4.85	31.35	10.40	41.75

Cost A: Includes inspection, cleaning, assembling and filling. 2 men at $4.25, and 6 men at $3 for 1 day — $26.50 for 2,000 k. w. transformer. 1 man at $4.25, and 3 men at $3 for 1 day — $13.25 for 100 k. w. transformer.

Cost B: Includes testing and connecting high and low voltage terminals. 2 men at $4.25, and 2 men at $3 for 1 day on 3 transformers.

Cost each transformer (1/3 of $14.50) $4.85 all capacities.

Cost C: Includes additional labor for assembling and for drying core and oil. Drying 3 — 2,000 k. w. transformers, 37,000 volts. 1 man at $4.25, and 3 men at $3, 1 day, preparation. 1 man at $3 per day for 6 days, attending.

Cost each transformer (1/3 of $31.25) $10.42.

Drying 3 — 100 k. w. transformers, 11,000 volts. 1 man at $4.25, and 1 man at $3 1 day, preparation. 1 man at $3 per day for 2 days, attending.

Cost each transformer (1/3 of $13.25) $4.42.

Cost of Installation of Electrical Rotating Machinery Up to 10,000 lbs., Transformers, Rectifiers and Regulators Less than 75 k. w. Table XVI gives costs for miscellaneous electrical machinery taken from appraisals by the authors.

Cost of Labor Installing Line Transformers. The following data are from an appraisal by the authors:

Size, k. w.	Cost of labor
0.6	$3.00
1.	3.10
1.5	3.30
2.	3.50
2.5	3.70
3.	4.10
4.	4.70
5.	5.30
7.5	6.50
10.	7.75
15.	9.70
20.	11.30
25.	12.80
30.	14.25
40.	16.75
50.	19.00
100.	28.00
150.	33.50
200.	37.50

The above costs include inspection, cleaning, assembling and fill together with the cost of distributing, cross-arming, hanging and connecting the transformers.

Cost of Setting and Moving Meters and Transformers. The following distribution and service expenses are shown in a recent analysis by the Pacific Power & Light Company given in Elec-

TABLE XVI. COST OF INSTALLATION OF ELECTRICAL MACHINERY

	H.-p. or k. w.	Voltage	Weight	Unpacking	Placing	Oiling	Connecting	Starting	Total
			$	$	$	$	$	$	$
Per cent of total			...	.10	.50	.10	.25	.05	....
Transformers	.6	2,200 V–110V	110	.11	.55	.11	.27	.05	1.10
....	10.	....	545	.54	2.72	.54	1.36	.27	5.45
Generators	3.75	115	525	.52	2.62	.52	1.31	.26	5.25
Motors d. c.	5.	115	525	.52	2.62	.52	1.31	.26	5.25
C. C. transformer..	4.	2,200	520	.52	2.60	.52	1.30	.26	5.20
Transformers	20.	2,300 110	1,025	.91	4.55	.91	2.27	.45	9.10
Generator	7.5	125	1,020	.91	4.55	.91	2.27	.45	9.10
Motor d. c........	10.	115	1,025	.91	4.55	.91	2.27	.45	9.10
C. c. transformer..	8.	1,100–2,200 (4 Amp)	985	.88	4.40	.88	2.20	.44	8.80
Transformer	30.	6,600–110	1,500	1.05	5.25	1.05	2.62	.52	10.50
Generator	10.	125	1,350	1.02	5.10	1.02	2.55	.51	10.20
Motors a. c. or 3 phase	25.	110–220	1,575	1.07	5.35	1.07	2.67	.53	10.70
Regulator — i. b. s.	17.5	2,200 (80 Amp)	1,345	1.02	5.10	1.02	2.55	.51	10.20
M. g. set	11.	125	1,600	1.07	5.35	1.07	2.67	.53	10.70
Generator	15.	110	2,400	1.20	6.00	1.20	3.00	.60	12.00
Motors — d. c.	30.	220	2,580	1.22	6.10	1.22	3.05	.61	12.20
C. c. transformer..	25.	2,300 (6.6 Amp)	2,200	1.17	5.85	1.17	2.925	.585	11.70
Regulator — i. r. s.	33.	2,200 (150 Amp)	2,625	1.23	6.15	1.23	3.075	.615	12.30
M. g. set	.5	125	2,500	1.21	6.05	1.21	3.025	.605	12.10
Transformer	250.	6.600 1150–2300	4,000	1.27	6.35	1.27	3.175	.635	12.70
Generator	45.	125	4,225	1.28	6.40	1.28	3.20	.64	12.80
Motors — d. c......	35.	220	3,900	1.27	6.35	1.27	3.175	.635	12.70
M. g. set	37.5	125	4,250	1.28	6.40	1.28	3.20	.64	12.80
Generator	50.	125	4,800	1.27	6.38	1.27	3.175	.635	12.70
Motors — d. c......	70.	220	5,500	1.29	6.45	1.29	3.225	.645	12.90
M. g. set	30.	125	5,000	1.29	6.45	1.29	3.225	.645	12.90
Generator	75.	220	8,000	1.50	7.50	1.50	3.75	.75	15.00
Motors — d. c......	100.	230	8,600	1.51	7.55	1.51	3.775	.755	15.10
M. g. set	30.	125	8,000	1.50	7.50	1.50	3.75	.75	15.00

trical World, Dec. 2, 1916. The average distribution cost per consumer for the year (1916) was $1.83. Lower costs ($1.53 up) existed in some districts, but expenses ran as high as $4.05 in other districts. Setting and removing meters and transformers on the average cost $0.55 per consumer, the minimum expense being $0.29 and the maximum $0.99. Meter maintenance averaged about 8.14 cts. per meter, although in some districts the expense went as high as 13 cts. and as low as 4.8 cts. Maintenance of installations varied from 5 to 88 cts. and averaged about 19.9 cts. The commercial expense per consumer had a range of $2.60 to $6.40 and averaged $3.48. It should be pointed out that all items making up the total expense of serving consumers are not included.

Cost of Installing Motor Generator Sets. The costs for generator sets weighing over 10,000 lbs., given in Table XVII, were derived by the authors from appraisal on the Pacific coast in 1910.

TABLE XVII. COST OF INSTALLING MOTOR GENERATOR SETS WEIGHING OVER 10,000 LBS.

Item	Per cent. of total cost	Unit, 120 k. w.	Unit, 500 k. w.	Unit, 1,000 k. w.
Voltage	...	2,400–150	4,300–550	11,000–550
Weight, lbs.	...	38,000	56,000	109,000
(1) Assembly	38.5	$23.90	$35.00	$68.20
(2) Leveling	3.5	2.20	3.50	6.20
(3) Grouting	7.5	4.65	7.00	13.30
(4) Cleaning	4.0	2.50	3.50	7.10
(5) Testing	8.0	4.95	7.00	14.20
(6) Connecting	9.0	5.60	8.15	15.95
(7) Drying	26.5	16.45	23.80	46.85
(8) Starting	3.0	1.85	2.80	5.30
Total	100%	$62.00	$91.00	$177.00
Cost per 100 lbs., all sizes				$0.16

Of these costs 53.5% are for assembling, leveling, grouting and cleaning — items (1) to (4) — and 46.5% are for testing, connecting, drying and cleaning — items (5) to (8).

Cost of Installing a 500 k. w. Motor Generator Set according to the figures given in Table XVII may be further subdivided as shown in Table XVIII.

TABLE XVIII. INSTALLATION OF 500 K. W. MOTOR GENERATOR SET

Item	Men at $4.25 per day	Men at $3 per day	Total hrs.	Cost
(1) Assembly	2	3	16	$35.00
(2) Leveling	1	3	2	3.31
(3) Grouting	1	3	4	6.62
(4) Cleaning	1	2	3	3.84
(5) Testing	2	2	4	7.25
(6) Connecting	1	1	9	8.15
(7) Drying	1	1	4	
		1	28	24.13*
(8) Starting	2	1	2	2.88
Total labor cost of installation				$91.18

* Includes $10 for power.

Cost of Installing 300 k. w. Motor Generator Set. The data in Table XIX are for an installation in the Southern States in 1913 and are from a recent appraisal by the authors. The costs are taken from accounting records.

TABLE XIX. INSTALLATION OF 300 K. W. MOTOR GENERATOR SET

	Material	Labor	Freight	Drayage	Total
1–3030 k. w. 3 bearing motor generator set, consisting of one 2,200 volt, 2-phase, synchronous motor directly connected to railway generator with direct-connected exciter — f. o. b. factory	$6,000	$180	$185	$27	$6,392
Switchboard, synchronous motor panel for 300 k. w. generator swinging bracket, lighting arrester, 8 disconnecting switches, f. o. b. factory	1,435	117	53	5	1,610
Connections to present buses	69	...	...	..	69
Cable and wire	228	65	...	..	293
Conduit and fittings	69	75	...	..	144
Rebuilding old buses	96	217	...	..	383
Total	$7,897	$724	$238	$32	$8,891

Cost of Installing a 500 k. w. Motor Generator in Washington. The following is the cost of installing a 500 k. w. motor generator in a light and power plant in Washington in 1906.

Material:

500 k. w., 500 rev. per min. motor generator	$ 9,200.00
Switchboard and switching apparatus	1,725.00
Freight on generator and switchboard	1,200.00
Wire	64.61
Miscellaneous material	160.75
60 ft. 13,000 volt, 3 cond. cable	129.00
490 lbs., 1,000,000 C. M. S. B. W. P. cable	151.90
Cost of material	$12,631.26

Labor:

Setting up machine	$ 116.39
Setting up switch, machine pipe supports, insulators and compensators	131.65
All 13,000 volt wiring	176.06
A. c. controller and instrument wiring, setting up a. c. panel and running motor field wire	94.00
All d. c. wiring not included above	94.35
Miscellaneous	4.20
Cost of labor	$ 616.65
Total cost of installation	$13,247

Cost of Installing 1,000 k. w. Turbo-Generator and Auxiliaries. The data in Table XX are for an installation in the Southern

States in 1913 and are from a recent appraisal by the authors and are actual costs taken from accounting records.

TABLE XX. INSTALLATION OF 1,000 K. W. TURBO-GENERATOR AND AUXILIARIES

	Material	Labor	Freight	Drayage	Miscellaneous material, etc.	Total
Excavating, clearing, etc.		$ 147	....	...	$ 10	$ 157
Basement floor, patching, turbine floor		62	....	$ 3	50	115
Contract, building turbine and auxiliary foundations		.....	....	...	...	1,250
Piping	$3,313	525	$155	32	17	4,042
1–1000 k. w. G. E. Co. turbo-generator, erected.	13,100	210	....	...	110	13,420
* Auxiliaries, f. o. b. plant	7,300	105	....	...	201	7,606
1 oil switch, 500 ampere, 7,500 volts, 4 pole single throw complete — f. o. b. factory....	387	163	25	...	212	787
Total	$24,100	$1,212	$180	$35	$600	$27,377

* Auxiliaries consisted of one surface condenser of 2,900 sq. ft. cooling surface, one 7 by 14 by 14 in. rotary dry vacuum pump, one 2 in. centrifugal hotwell pump, and one 10 in. centrifugal pump.

Cost of Installing 2,000 k. w. Turbo-Generator, Boiler, Superheater and Other Auxiliaries. The data in Table XXI are for an installation in the Southern States in 1914–15 and are from a recent appraisal by the authors. The costs are taken from accounting records.

Cost of Foundations for Two 500 k. w. Generators. The cost of foundations for two 500 k. w. direct connected, engine driven generator units built by contract for a power house in Washington in 1906 was $2,480. There were 320 cu. yds. of granite masonry placed at $7 per cu. yd.

Cost of Foundations for a Turbo-Generator. The cost of foundations for a 750 k. w. turbo-generator built by contract in Washington in 1906 was $313.05, divided as follows:

	Unit cost
12.8 cu. yds. concrete, per cu. yd.	$10.00
1,638 brick, per M in place	33.85
8–15 in. I beams 10 ft. long weighing 3,360 lbs., per lb. in place	.045

The foundation consisted of one concrete slab and four brick columns.

Cost of Foundations for a Rotary Converter. The cost of foundations for a 250 k. w. alternating current rotary converter built

by contract in 1906 in a power house in Washington was $113.76, divided as follows:

340 lbs. cast iron, per lb. in place	$.035
2,268 lbs. steel, per lb. in place	.045

TABLE XXI. INSTALLATION OF 2,000 K. W. TURBO-GENERATOR, BOILER, SUPER HEATER AND OTHER AUXILIARIES

Item.	Material	Labor	Freight	Drayage	Miscellaneous material, etc.	Total
1–600 h.-p. boiler erected	$7,095	....	....	...	....	$8,650
1–600 h.-p. superheater, erected	1,555	....	....	...	....	.....
Boiler setting, fuel oil system, foundation footings, damper regulator, installed	2,503	$221	$2	$3	....	$2,729
1–2,000 k. w. turbo-generator, f. o b. erected	21,500	518	....	...	$252	22,270
* Auxiliaries	8,578	159	....	3	31	8,771
1–500 k. w. motor generator set, f. o. b. factory	6,100	83	476	34	28	8,546
1–50 k. w. turbine driven exciter, f. o. b. plant	1,825	....	....	...	....	.....
Switchboard, f. o. b. factory	1,647	1,668	160	6	1,198	5,402
Wiring	723	....	....	...	....	.....
Total	$51,526	$2,649	$638	$46	$1,509	$56,368

* Auxiliaries consisted of: One 4 in. 3-stage, double suction, turbine boiler feed pump, direct connected to and mounted on a special cast iron base with turbine, f. o. b. plant, cost $1,200. B. and W. No. 18 gauge condenser tubes, 17,700 lin. ft., f. o. b. plant, cost $1,878. One condenser equipment for a 2,000 k. w. turbo-generator unit, the equipment to consist of one 4,400 sq. ft. surface condenser without the tubes, one 9 in. and 18 in. by 16 in. rotary vacuum pump and one 3 in. turbine driven, centrifugal hotwell pump, f. o. b. erected, cost $5,500.

Cost of Erecting a 300 k. w. Motor Generator. Kent gives the following cost of a temporary installation of a 300 k. w. motor generator.

	Unit cost
Labor:	
Moving and erecting machine	$118.50
25,000 volt wiring, including hauling	20.80
2,300 volt wiring, including oil switch	37.90
600 volt wiring, including panel and pedestal	60.50
Machine foundation and anchor bolts	21.80
Time of shop men	8.36
Material:	
Wire	48.09
Miscellaneous material	16.17
Total cost of erecting generator	$332.20

Labor Cost of Installing 850 k. w. Generator and Exciter. The following is the labor cost of installing an 850 k. w. generator and exciter in a light and power plant in Washington in 1909.

	Cost
Setting up exciter	$ 68.50
Exciter wiring	8.75
Wiring for motor and motor panel	67.50
Setting up generator	267.10
Wiring for generator and panel	127.50
Draftsman	117.37
Machine foundation, floor, retaining walls, etc.	1,032.42
Total labor cost of installation	$1,688.74

Cost of Installing and Testing Meters. One meterman at $2.70 per day can inspect and test 10 Thompson recording watt meters, or 20 Type G meters in a day. He can install 8 meters per day.

	Thompson meters	Type G meter
Testing	$0.27	$0.14
Installing	0.34	0.34
Total cost per meter	$0.61	$0.48

Cost of Underground, Cypress Fuel Oil Tank. The cost of a cypress fuel oil tank built in the Southern States in 1912 as taken from a recent appraisal by the authors was as follows:

Excavation	$200
Cypress tank, 6 x 1 x 40 ft. long	262
Pipe fittings	48
Cost complete	$610

The cypress tank had a foundation of cedar and was covered with a cedar top. The pipe fittings consisted of miscellaneous pipe, unions and Ts and 5 valves.

Cost of Installing Tools and Equipment in a Smelter. See chapter on Buildings.

Cost of Installing Miscellaneous Tools. See Miscellaneous chapter.

Cost of Installing Milling Equipment. H. T. Curran (Engineering and Contracting, Oct. 6, 1915) states that poorly stored machinery may easily add several dollars per ton to erection costs. An experienced engineer will size up the job and divide the material into different classes. It is then usually figured on a tonnage basis. Generally speaking, the heavier the piece the less the erection cost per ton. Steel tanks over ⅜ in. thick can be erected for $35 per ton; and ⅜ in. or less from $40 to $45 per ton. To place engines, stamps, crushers, pumps, to line up shafting, set electric motors, including wiring, etc., the cost will be about $45 per ton of iron; to set up concentrating machinery, classifiers, filters, etc., from $50 to $65 per ton. These figures cover the necessary carpenter work, placing pulleys, belts, and ad-

justments. When the carpenter work is figured separately these figures are high. Under these conditions it will cost from $25 to $30 per ton of iron to place engines, stamps, crushers, line up shafting, etc. To set up concentrating machinery, classifiers, filters, etc., costs from $30 to $45 per ton. This of course includes placing pulleys, belts and adjustments. The pipe work in the average mill will cost from $40 to $45 per ton. Erecting wooden tanks costs around $12 per M. Reduction works constructed wholly of steel are now becoming popular where the winters are not too severe. Framework of steel can be erected for $12 to $15 per ton by contract. A good contractor with a crew of construction men will make money at these figures.

Cost of Preliminary Work in Mill Construction. H. T. Curran (Engineering and Contracting, Oct. 6, 1915) states that after it has been determined just what kind of a plant is needed, and after the site has been selected and the drawings made, a thorough organization of plans should be established and every detail gone over in the mind's eye.

The first step is to estimate the yardage to be excavated, the amount of masonry or concrete work required, and then a complete list of all material should be made. The tendency is to overlook a multitude of small things which have considerable value in the aggregate. To the machinery specifications should be added a complete list of lumber, doors, windows, all hardware down to nails, pulleys, belts, lime, sand, broken rock — in fact everything that goes into the construction. The cost and weight of this can readily be determined by consulting reliable dealers and adding the necessary freight charges.

The next step should be the working out of a thorough development plan and an estimate of its cost. Everything should be made ready, so that when actual construction starts there will be neither confusion nor delay. The cost of this work is considerable and it is often neglected, with the consequent addition of excessive costs to some other part of the work. A great amount of future trouble and worry can be avoided by a careful planning for a few important features, which will be mentioned.

Unloading facilities and material and tools to do it with should be provided. A good road to the plant should be built and convenient deliveries arranged for. It is a noticeable fact that many a well constructed mill has such poor facilities for receiving supplies that the extra cost for a year would probably build everything needed to make such work easy and cheap. Ample room ought to be set aside for timber yards and all lumber should be marked and piled so that a glance will determine just what part of the job it was bought for.

A handy place should be marked off for a storage house and its cost estimated. It is surprising what a number of small things will be lost or misplaced without such storage. Roomy framing plots, as level as possible, should be marked off and handy places for machinery storage determined, keeping in mind pieces which will be first used and their situation. The supply of gravel, sand

and rock must be looked into and arrangements made for its cheap delivery at any point. All details for disposing of rock and earth excavated with the least possible amount of handling should be planned.

The labor question must be studied and complete arrangements made for the comfort of the men. Their efficiency will vary directly with the conditions of their surroundings. Recently, in the west, a so-called mining man who had never given human nature a moment's thought attempted to build a mill in an out-of-the-way place with no fit accommodations for anyone but himself. The results were disastrous for the company. Good men could not be kept and the mill was finished up at an excess in cost of more than $50,000. Some of the tanks collapsed on their foundations with the first filling.

The cost of all this preliminary work can be estimated by the man on the ground; it averages from 5 to 10% of the total. If it is neglected, confusion and delays throughout the job are the inevitable result. Good organization is just as essential to the construction of a plant as to its operation.

Cost of Miscellaneous Foundations. The following costs of the foundations for an electrolytic lead refining plant at Grasselli, Ind., are taken from Engineering and Contracting, Mar. 12, 1913.

Cost of Engine Foundations. These foundations consisted of heavy blocks of concrete built in pits excavated in sand to 4 ft. below the level of the ground. The blocks extended 6 ft. above ground level. Excavation and concreting are included in the costs given but not the forms. The work was begun June 7 and completed July 6. The wages were 37.5 cts. per hour and the concrete was hand mixed.

Concrete, cu. yds.	399.2
Total cost	$946.20
Labor cost per cu. yd.	2.37

Cost of Furnace Foundations. This concrete was placed in small excavations 4 ft. deep and no forms were employed.

Concrete, cu. yds.	399.2
Total cost	$106.80
Labor cost per cu. yd.	1.70

Cost of Power House Foundations. The concrete foundations for the building consisted of a wall about 20 ins. wide and 4 ft. deep in sand under the four walls of the building. No forms were used. The boiler foundations were simply large square blocks of concrete 4 ft. deep.

Concrete, cu. yds., in boiler foundations	53
Concrete, cu. yds., in building foundations	118
Concrete, cu. yds., total	171
Total labor cost	$501.50
Cost of labor per cu. yd.	2.93

Cost of Pump Foundations. These were foundations for boiler feed pumps, centrifugal pumps for the condensers, and foundations

for the feed water heater. They were small blocks of concrete set in the sand and extending about a foot above the ground. Boxes were made with templates for the foundation bolts.

Concrete, cu. yds.	22.4
Total labor	$73.20
Cost per cu. yd. labor	3.27

Cost of Scale Foundations. These foundations were for a narrow-gage track scale of the Howe type and they were built within one of the buildings and required 3 days' work:

Concrete, cu. yds.	23.4
Total cost of labor	$30.80
Cost per cu. yd.	1.30

Cost of Tank House Foundations. These foundations were about 20 ins. wide and 4 ft. deep and were built to support the walls around a building 72 × 360 ft. in plan. There were also piers supporting the steel columns at 18-ft. intervals. The excavation amounted to 365 cu. yds. of sand and is also included.

Concrete, cu. yds.	287
Total labor	$611.60
Cost per cu. yd.	2.13

Cost of Erecting Miscellaneous Machinery. E. H. Jones (Bulletin of American Institute of Mining Engineers, July, 1914) gives in Table XXII the erection costs of machinery of the Arizona Smelter Co., Clifton, Ariz. The costs of buildings for this plant are given in the chapter on Buildings.

TABLE XVIII. COST AND ERECTION OF MACHINERY FOR A SMELTER

	Weight, lbs.	Labor cost per 100 lbs.	Erection cost per 100 lbs.	Total cost	Per 100 lbs.
	GROUP NO. 1				
1. Two electrical feed pumps	43,345.	$0.87	$0.87	$6,187.56	$14.28
2. Six No. 14 Wilgus oil systems	8,475.	1.32	1.46	1,973.77	23.29
3. Steam feed pumps	3,547.	1.05	1.07	499.24	14.07
4. Two Nordberg blowers with air receivers	383,242.	0.43	0.80	34,155.64	8.91
5. Three Curtis turbines and ten auto transformers	454,140.	0.51	0.98	81,884.19	18.03
6. Two dry vacuum pumps for jet condenser	24,200.	1.18	2.14	3,145.52	13.00
7. Two circulating pumps	37,560.	0.98	1.15	3,902.58	10.39

	Weight, lbs.	Labor cost per 100 lbs.	Erection cost per 100 lbs.	Total cost	Per 100 lbs.
8. Air compressor ...	97,840.	0.66	0.81	....	....
9. Three dry vacuum pumps	14,000.	1.05	1.42	$3,337.36	$23.84
10. Three pumps and engines	97,255.	0.40	0.58	9,118.69	9.38
11. Two 5 by 8 vertical triplex pumps..	11,354.	1.55	1.72	2,211.78	19.48
	1,174,958.	$0.55	$0.92	$146,416.33	$13.59
		GROUP No. 2			
12. Two 40-ton Morgan cranes	221,500.	$0.65	$1.72	$23,027.65	$10.40
13. Two clinkering machines	169,213	1.01	1.44	15,697.17	9.28
14. Two casting machines	269,220.	1.21	1.37	27,477.55	10.21
	659,933.	$0.97	$1.50	$66,202.37	$10.03
		GROUP No. 3			
15. Farrell crusher, 36 by 18	50,000.	$0.79	$0.80	$1,486.47	$2.96
16. Two motor-driven fans at roaster building	6,140.	1.27	1.32	1,483.60	24.16
17. Traveling hand crane, 5 ton...	3,000.	0.84	1.50	589.55	19.65
" 20 ton...	25,200.	0.52	0.67	1,855.16	7.36
18. Three surface condensers	115,700.	0.36	0.47	19,978.86	17.27
19. One barometric condenser	8,132.	1.59	2.28	1,078.65	13.26
	208,172.	$0.56	$0.68	$26,472.29	$12.72
		GROUP No. 4			
20. Two exciters	54,300.	$0.90	$1.59	$6,609.27	$12.17
21. Two 150 kw. synchronous generator sets	41,898.	0.76	1.67	7,149.39	17.09
	96,198.	$0.84	$1.63	$13,758.66	$14.30

Group 1 contains the erection of engine machinery. It was here necessary, in addition to handling heavy weights and placing on the foundation, to clean, adjust, and line up many mechanical parts. Group 2 is very similar to 1, but the machinery is not of the engine type and not so heavy in proportion to the labor required to put it in working order. Group 3 composes machinery that required little other labor in the main than the lifting of heavy loads into place. Group 4 is somewhat similar to Group 3, but the labor is principally electrical. The above costs are reported as labor, erection, and total costs. The labor cost is self-explanatory. The

erection cost is the labor cost plus the needed small supplies, such as waste, oil, small tools, and the like. The total cost is also self-explanatory. Further details relating to the machinery in Table XVIII are given in the following notes.

(1) *Two Electrical Feed Pumps* located back of the boilers were lowered into the 13-ft. pit onto their foundations and set ready for piping connections. They are two vertical triplex, 8- by 10-in. Aldrich, electrically driven pumps each attached with flexible couplings to a 40-h.p. motor. The cost covers the material segregated below and the labor of installing the same:

	Factory	Freight	Total
Two 40-h.p. motors	$1,700.00	$24.44	$1,724.44
Two vertical triplex pumps	2,794.00	547.07	3,859.07
Spare parts for pumps	518.00		
Miscellaneous			50.46
			$5,633.97

In wiring the two 40-h.p. motors of the feed pumps to the mains the material was as follows:

2 circuit breakers	$ 31.70
Conduit and covering	85.20
Wiring and miscellaneous	60.99
	$177.89

(2) *Six No. 14 Wilgus Oil Systems.* This account covers the cost of 6 Wilgus oil pumps, asbestos covering for portions of these pumps, the labor of installing the pumps, the labor of thoroughly overhauling them, required because of the unsatisfactory condition existing in the leaking steam heating coils and the labor of applying the asbestos covering. The 5¼- by 3½- by 5-in. duplex oil pumps were set directly on the concrete floor in front of the oil-fired boilers.

(3) *Steam Feed Pump.* Here is given the labor of installing and the material cost of one 10- by 6- by 12-in. duplex boiler steam feed pump. This pump is located next to the two electrically driven Aldrich pumps.

(4) *Nordberg Blowers — Cost and Installation.* This account covers the cost of the material as listed below, together with the labor of erecting. Engines are two Nordberg cross-compound blowing engines, designed to compress 10,000 cu. ft. of free air at an altitude of 3,500 ft. to 12 lbs. pressure, while 15 lbs. may be carried if desired. The high-pressure steam cylinder is 20 ins., the low-pressure 42 ins., while the air cylinders are 44 ins., all having the common stroke of 42 ins. The engines are furnished 160 lbs. steam pressure, superheated 75 degs. F. The speed is 71 r.p.m. The labor of grouting, and the labor of testing out and starting up are included.

2 Nordberg blowing engines, with receivers	$30.967.34
2 No. 34 crane tilt traps	107.78
Grout, etc.	1,438.90
	$32,514.02

(5) *Turbines — Cost and Installation.* This account covers the purchase price of three Curtis turbines and material as listed below, together with the labor of erection, grouting, wiring from generator to switchboard, testing and starting up. The turbines are 2,000-k.w. Curtis-type horizontal shaft engines and direct connected to 2,500-k.v.a., 6,600-volt, 60-cycle, 3-phase, 1,900-r.p.m. generators. The approximate size of each unit is 23 ft. 8 ins. long by 10 ft. 6 ins. wide by 9 ft. 7 ins. high, with a net weight of 108,300 lbs.

3 turbines	$77,828.10
486 gallons of gargoyle turbine oil	233.04
Grout, electrical material	1,525.35
	$79,586.49

(6) *Jet Condenser — Dry Vacuum Pumps.* These air pumps remove the air from the barometric condenser and are located in the power house. The account covers the cost of the material listed below and the labor of erecting the same.

Two 15-h.p. slip ring motors, 440 volts, 3 phase, 60 cycles, 565-r.p.m., with resistance controllers	$ 739.92
Two 16 by 12 single-stage Alberger dry vacuum pumps	1,888.82
2 circuit breakers	39.88
Grout, cable, condulets, etc.	191.99
	$2,860.01

(7) *Circulating Pump — Cost and Erection.* These air pumps furnish the circulating water for the barometric condenser. The cost includes the price of the material listed and the labor of installing.

Two 35-h.p., 440-volt, 60-cycle, 570-r.p.m. motors	$1,687.50
Two 2 Lobe cycloidal jumps, 14 by 12, 17.8 gal. per rev.	2,341.41
2 oil switches, 660 volt	39.89
Miscellaneous	66.88
	$3,535.68

(8) *Air Compressor — Erection.* This account covers only the erection at the smelter of the following Ingersoll-Rand two-stage compressor. It was brought from the mines and erected at the smelter power house. The compressor has a steam-driven cross-compound Corliss engine. The steam cylinders are 13 in. and the air cylinders are 22 in. and 13 in. and the common stroke is 36 in.

(9) *Three Dry Vacuum Pumps — Cost and Installation.* These pumps are for the surface condensers. The account covers their cost, erection, grouting and trying out. They weighed 14,000 lbs.

3 dry vacuum pumps 8-in. steam by 20-in. air by 12-in. stroke	$3,136.11
Grout, packing, etc.	53.99
	$3,190.10

(10) *Three Circulating Pumps and Engines — Cost and Installation.* These pumps furnish the circulating water for the surface

condensers. The account covers the cost of the material licted below and the labor of erecting and trying out.

3 Lobe, 18 by 20, cycloidal pumps, capacity 49.5 gallons per rev., and three 27-in. flexible couplings	$4,425.25
Three 11 by 14 Ridgway, simple balanced, slide-valve engines for direct connection to above pumps	4,124.60
Grout, packing, etc.	179.43
	$8,729.37

(11) *Pumps.* This account covers the cost of the following material and its erection in the pump house.

Two 5 by 8 Aldrich vertical triplex, single-acting pumps, 37 r.p.m. with metallic packing	$1,597.91
Two 10-h.p. induction motors, squirrel-cage, 3-phase, 60-cycle, 440-volt, 850-r.p.m.	287.22
2 auto starters	.....
2 overload releases calibrated from 6 to 18 ampere per terminal	124.36
Miscellaneous	26.09
	$2,035.58

(12) *Cranes.* This covers the cost of two 40-ton Morgan cranes and the labor of installing them on the craneway, and putting together the equipment ready for operation. It does not include the wiring. They were hoisted in place on the craneway by the use of two erecting engines. These cranes are of 40-ton capacity, have 4 four motors, span 55 ft. from rail to rail, and are rigged for a 50-ft. lift. Each crane has a 15-ton auxiliary hoist.

(13) *Clinkering Machines.* These two machines are set 24 ft. above the floor of the converter building on structural steel supports. The steel supports are a part of the converter building and have been costed in that account. The main body of the machine, the mixer, is the frustrum of a cone 13 ft. 6 ins. long, whose head end is 5 ft. diameter and whose discharge end is 9 ft. 6 ins. diameter. It is made of ¾-in. steel plate, lined with 1-in. cast-iron liners. The whole is mounted on trunnions operated by a 50-h.p. motor. The ladle which feeds the converter slag into the head end is 60 cu. ft. capacity and is tilted by a screw operated by a 15-h.p. motor.

The feeder which lets siliceous ore into the head end to agglomerate with the slag extends from the silica bins to a pipe discharging into the dropping stream of slag. It is a screw conveyor 4 ft. 9¼ ins. long. Each machine has a hood connected to a steel flue 2 ft. 6 ins. diameter by 36 ft. 8 ins. long, leading into the converter dust chamber.

The machinery for two machines enumerated above cost	$11,872.82
Two 50-h.p. motors as above	828.61
Two 15-h.p. motors as above	820.16
2 brakes for ladle tipping motor	176.51
2 traveling switches for brakes	136.44
2 circuit breakers	102.80
Miscellaneous	44.60
	$13,981.94

This cost includes the price of the machines and the cost of installing them.

(14) *Casting Machine — Cost and Erection.* This account covers the cost of all the material composing 2 casting machines, and all the labor required to erect on their foundations ready to operate. Each machine has a steel cradle to receive a ladle of molten copper. This cradle is controlled from a pulpit and is tipped by the power from a 20-h.p. motor. It is set high enough to pour into a casting spoon of 1½-in. cast iron whose approximate dimensions are 2 ft. wide by 3 ft. 6½ ins. long, and from 7 ins. to 1 ft. 5½ ins. deep. This casting spoon pours into the moulds, which are attached to a heavy steel conveyor. The moulds are 39 in number, made of 2½-in. cast iron reinforced with 5/16-in. perforated plate. Their inside dimensions are 2 ft. 4 ins. by 1 ft. 6¼ ins. by 3¼ ins. deep. From the pulpit, by use of power from a 20-h.p. motor, the conveyor with the moulds moves along under a spray of water from needle holes in pipes placed above them until they reach the end of the conveyor, where a device in the bottom of the moulds loosens the ingots, allowing them to drop into a tank of water. This bosh is made of 5/16-in. plate, 3 by 3 and 4 by 3 angles. It is 7 ft. wide, 23 ft. 5¾ ins. long, and varies in depth from 7 ft. 10 ins. to 2 ft. 10 ins. The copper bars are removed from here by a steel drag conveyor operated by a 11-h.p. motor, controlled from the pulpit. When the bars leave the bosh and fall onto the striking plate they are handled by a radial crane whose moving end travels on a 40-ft. curved I-beam. Along the radial crane beam travels a small air hoist capable of picking up 1 ton. It operates under an air pressure of 16 lbs. A jib crane is so located, attached to a building column, that it can handle the moulds for removing and replacing. It has a 3,000-lb. capacity triplex block and 8-in. I-beam trolley. Below is a segregated material list:

2 casting machines	$18,657.89
Two 11-h.p. and four 20-h.p. motors	2,933.88
2 jib cranes	327.22
2 radial cranes	1,167.91
2 traveling switches	135.75
2 brakes for ladle tipping motors	176.51
4 circuit breakers	103.50
Moulds, etc.	708.55
	$24,211.21

(15) *Crushing Machinery.* This account covers the material cost and labor of installing the following machinery:

One 36-in. by 18-in. Farrell Crusher, second hand, weight 50,000 lbs.	$1,000.00
Miscellaneous lumber	93.61
	$1,093.61

(16) *Motor-driven Fans.* This covers the price and cost of installing upon their foundations 2 motor-driven fans, which furnish

the air to cool the roaster arms. They are 55-in. double width, full housing conoidal fans, direct connected, each with a 25-h.p. squirrel-cage induction motor.

Each fan has a capacity of 22,000 cu. ft. of air per minute against a pressure of 1¾ ins. water.

	Cost	Freight	Total
2 fans and motors......	$1,203.00	$199.49	$1,402.49
Miscellaneous			3.42
			$1,405.91

(17) *Crane.* This covers the purchase of the crane listed below, the labor of overhauling and erecting it.

One 5-ton hand power traveling crane, chain block transfer type 18-ft. span, complete with roller bushed geared trolley and provided with 5-ton triplex chain block for 13 ft. lift	$378.35
Miscellaneous	60.06
	$438.41

(18) *Condensers — Cost and Installation.* This covers the cost of 3 Alberger surface condensers and the labor of placing and grouting them in position. Each condenser has 7,600 sq. ft. of surface.

3 Condensers	$19,436.04
Grouting, etc.	127.51
	$19,563.55

(19) *Jet Condenser — Cost and Erection.* This covers the cost of one 28-in. Alberger type "F," barometric jet condenser and erection above a tank.

(20) *Jet Condenser — Hot Well Supporting Structure and Tank.* This account covers the cost and erection of 5.76 tons of steel. There was a quadrangular tower 19 ft. 6 ins. high, with about 12 ft. base, surmounted with a 10 ft. diameter by 8 ft. 6 in. high steel tank.

(21) *Two Motor Generators — Cost and Installation.* This account covers the material listed below as well as the labor of unloading, erecting, grouting, wiring to switchboard, and trying out.

Two 150-k.-w. synchronous motor-generator sets to supply 250 volt d.c.	$6,450.16
Conduit and wire	317.36
Miscellaneous	62.81
	$6,830.33

Installation of Pelton and Doble Wheels of 3,000 to 4,000 h. p. in general takes about 30 days' time of an erecting engineer at $10 a day and expenses and 6 men at $2.50 to $3 per day, making a total cost for the installation of about $1,100, or $50 per ton.

Weight of Electrical Apparatus and Prime Movers. Leonard A. Doggett (Electrical World, May 3, 1913) gives curves of approximate weights prepared after consulting the bulletins of American

and European manufacturers, periodicals and textbooks, the only requirement being that the data must be less than 10 years old and preferably not over 5 years. See Figs. 3, 4 and 5.

Logarithmic paper was used, because it gives straight line plots and is economical of space. Curves of this nature can easily be interpolated as the dotted curves, whereby the weight of the smallest motors and transformers can be easily estimated. In

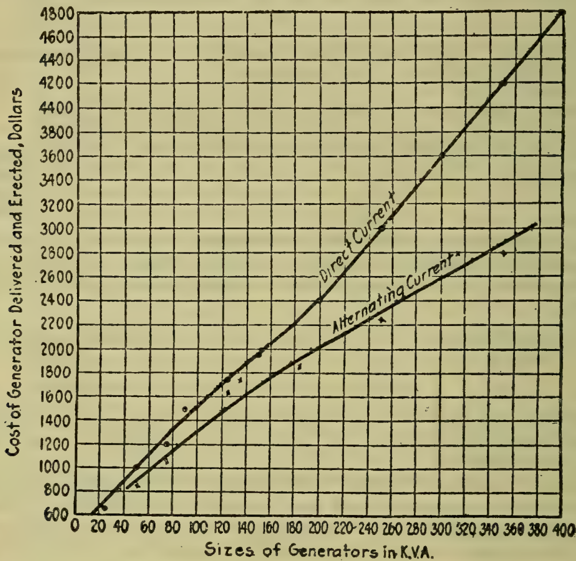


Fig. 3. Cost of directly connected engine driven D. C., and A. C., generators installed under ordinary conditions, bases being furnished by engine contractor.

using the curves it should be noted that for transformers the upper scale is to be used. For the machines "pounds" means weight of active material plus weight of shaft, spider, bearings, etc.; in other words, the total weight of the machine. In the case of alternators the abscissas are (kva.) ÷ (r.p.m.); for induction motors (kw. output) ÷ (r.p.m.).

Any of these curves for electrical apparatus can be expressed in the form of an equation, for example:

Weight in pounds of a transformer, including case and

$$\text{oil} = 1800 \left(\frac{\text{kva.}}{\text{frequency}} \right)^{3/4}$$

Setting Horizontal Return Tubular Boilers. The following data are abstracted from a publication of The Bigelow Company, New Haven, Conn. The first thing necessary to secure a setting that will remain tight and free from cracking is a good foundation. This should be prepared before the arrival of the boiler. When a boiler arrives it should be carefully unloaded and transported to the site of erection. One should remember that it is made up of a number of plates riveted together, and that the tightness of each tube depends upon two expanded joints; therefore a boiler should be handled with care. Pipes or bars should never be stuck in the tubes to aid in moving the boiler.

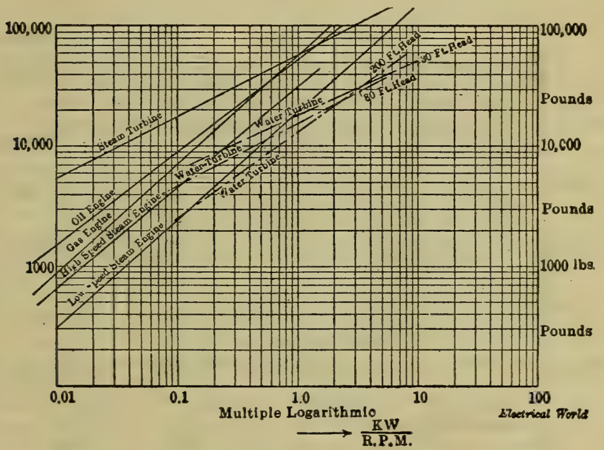


Fig. 4. Curves for obtaining approximate weight of prime movers.

Place the boiler in the correct position with the front properly set up before commencing the brickwork. When a boiler is to be supported on lugs resting on the brickwork, place it ½ in. higher than the desired final position, to allow for lowering on the brickwork when the supports are removed. If a boiler is to be hung from beams it can be placed in the correct position at once. No weight should be carried by the boiler front. To insure against this leave ⅜ to ½ in. clearance between the bottom of the shell and the front. This is especially important in the lug-supported type in order to allow for settling.

The front end of a boiler should be set 1 in. higher than the rear to aid in draining through the blow-off pipe when washing out. This also allows an extra inch depth of water over the rear tube ends, a precaution against damage from low water. In leveling a boiler crosswise consider two points, the top line of tubes and the face of the steam nozzle.

Barrels are preferable to blocking for supporting a boiler while the setting walls are being built, for they are less in the way of the masons. Two heavy oil barrels will support a 66-in. by 16-ft. boiler, if the blocking below them and on top is arranged so that the load is distributed evenly over all the staves. Use more barrels for larger boilers and arrange the blocking on top so that the load will be distributed evenly between the barrels. If good barrels are not available, a cribwork of blocks placed under the front and rear of the shell will serve the purpose. Care should be used in the arrangement of the blocking so that it will not interfere with the building of the setting walls.

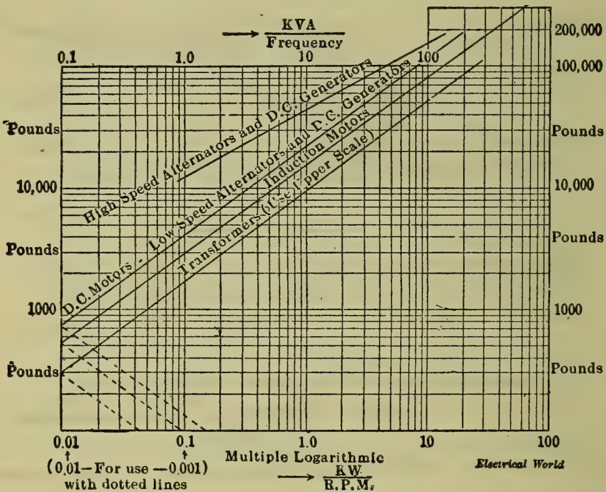


Fig. 5. Curves for obtaining approximate weight of electrical apparatus.

Some masons use common lime mortar in building boiler settings, but a much better and more lasting job can be obtained by adding cement to the bonding mixture. First mix regular lime mortar, using ¾ cu. yd. of good, sharp sand to 1 bbl. of lime. Then make a mixture of sand and cement, using 2 bbls. of sand to 1 bbl. or 4 bags of cement; add this to the lime mortar and then it is ready for use, and this quantity should be enough to lay about 1,000 bricks. If all the mortar cannot be used at once, the sand and cement mixture should be added only to such portion of the lime mortar as will be required for immediate use. It is difficult to keep it in proper condition for use overnight after the cement has been added. Fire-clay only should be used for bonding, in laying fire-brick. For this purpose mix it with water to about the consistency of buttermilk, so that the bricks may be

dipped in it and rubbed together when laying them. About 2 bbls. of fire-clay are required to lay 1,000 bricks.

To estimate the amount of common bricks required for a boiler setting, figure the number of cu. ft. of wall to be laid with this kind of brick, and multiply by 23; the result will be the number of bricks required. In making calculations no deductions should be made for openings in the setting walls for cleaning doors, etc.; the waste from breakage and cutting will require the extra brick figured in this way. Where fire lining is laid 4½ ins. thick and with every sixth course a header, figure 8 fire-bricks for each square foot of wall surface lined in this manner. If the lining is to be 9 ins. thick and with every sixth course tied to the common brick with a header, figure in 15 bricks for every square foot of wall surface lined.

Return tubular boilers are set with an air-spaced wall. This lessens the radiation losses by keeping down the temperature of the exposed wall surface. The chief advantage of the air-space construction, however, is that when properly built it tends to prevent the cracking of the outer wall surface and therefore makes a better-looking setting. An important point in the designing of setting walls, to prevent cracking, is the method used to join the ends of the bridge wall with the side walls. Usually a mason will build the two at the same time and tie the bridge wall rigidly to the side walls. This will result in cracked side walls, because the bridge wall expands when heated and pushes out the side walls. With the wall having an air space this does not necessarily show on the outer wall unless the two are tied together at this point.

There are two ways of preventing trouble from expansion of the bridge wall, one by leaving the ends of the bridge wall about an inch away from the side walls, packing the space with asbestos or mineral wool. The elasticity of the packing allows for the expansion of the bridge wall and it prevents the space from becoming clogged with ashes and cinders. The other way is to build a recess about 4½ ins. deep in the side walls having the same shape as a vertical section of the bridge wall, and build the ends of the bridge wall into this recess, leaving 1½ ins. of clearance at each end for expansion.

The chief function of a bridge wall is to limit the length of grate surface by presenting a barrier beyond which the spreading of the fuel is prevented; it also aids in mingling the unburned gases and air, so as to cause complete combustion before reaching the tubes. Where girth seams are located in the vicinity of the bridge wall, the top of the wall should be so shaped and of such a distance below the shell that the products of combustion will not strike directly against the seam. Leave at least 10 or 14 ins. between the top of the bridge wall and the shell to prevent overheating of the sheets, even in the absence of seams. The top of the bridge wall should be built straight across, and not follow the contour of the shell as is sometimes done.

The combustion chamber at the rear of the bridge wall is a very important feature. It aids complete combustion, especially if

bituminous coal is used. The rear edge of the bridge wall should be built vertically, and the space behind it down to about the level of the floor should be left open. The deep combustion chamber at the rear of the bridge wall causes a whirl in the air and gases coming over it and greatly aids in their proper mixture. It also increases storage capacity for the fine ash and cinder that is carried beyond the bridge wall.

The practice of filling the space behind the bridge wall cannot be too strongly condemned, for it seriously interferes with the accessibility for inspection of the most important surfaces of the boiler, and is certain to prevent complete combustion, especially if bituminous coal is used. It is easier to clean out the combustion chamber by arranging the bottom of it so that the blow-off pipe passes out below the paving. The cleanout door, which is usually located in the rear wall, should be placed on a level with the paving so that no obstacle is offered to raking out the ashes. Place the blow-off pipe in a brick trough, the bricks on top being arranged so that they may be readily removed for inspection. This arrangement admits the blow-off pipe being placed above the boiler-room floor without interfering with free access to the cleanout door. The vertical section of the blow-off pipe should be protected from the direct impingement of the flames by use of a pipe sleeve over it.

Some engineers prefer to line all the inner surfaces that are swept by flame and heated gases with fire-brick, and while this makes a good and lasting setting it adds considerably to the cost. If the front wall and the side walls as far as the bridge wall are lined, together with the face of bridge wall, and the balance of the setting is laid with good, hard-burned red brick, a satisfactory and very durable job will result. Every fifth or sixth course of fire-brick should be a header course to properly bind the lining to the main wall. When laying the fire-brick care should be taken to use only the minimum amount of fire-clay for bonding.

When a boiler is set with a Dutch oven, there is absolute need of binder bars or their equivalent to carry the thrust of the arch, but no such need exists with the ordinary return tubular setting where the boiler is hung, and probably not where the boiler is supported by lugs resting on the setting walls.

Proper provision to allow freedom for expansion of the shell must be made if the cracking of the setting walls is to be prevented. The walls should be left about 1 in. from the shell of the boiler at all points, and this space can be closed with asbestos rope or plastic asbestos to prevent air leakage into the setting. Pockets should be left in the brickwork around the rear supporting lugs so that there will be no chance for the lugs to push against the walls. A point where clearance is of vital importance is around the pipe connection to the water column and blow-off. Unless there is proper freedom allowed at these points there is danger of the piping being broken off.

Where boilers are hung from beams and supported on columns and more than one boiler is used, a column is often placed in the

TABLE XXIII. MEASUREMENTS FOR SETTING HORIZONTAL RETURN TUBULAR BOILERS WITH OVERCHANGING FRONT. (Fig. 6.)

Horsepower	Boiler: Diameter of Boiler	Boiler: Length of Boiler over All	Boiler: Length of Tubes	Boiler: Length of Curtain Sheet	Boiler: Size of Flue Uptake in Curtain Sheet	Boiler: Diameter of Dome	Boiler: Height of Dome above Boiler	Boiler: Height of Nozzles above Boiler	Boiler: Diameter of Nozzles	Furnace: Floor Line to Top of Grate at Front	Furnace: Floor Line to Top of Grate at Rear	Furnace: Top of Grate to Underside of Boiler at Front	Furnace: Length of Furnace	Furnace: Width of Furnace
	A	B	C	D		E	F	G		H	I	J	K	L
	In.	Ft. In.	Ft.	In.	In. x In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
16	36	8 11	8	11	7 x 32	20	20	5¼	4	25	23	26	36	30
29	42	11 0	10	12	8 x 36	24	24	5¼	4	25	23	28	42	36
48	48	13 2	12	14	9½ x 40	34	28	5¼	4	28	26	28	48	42
78	54	16 3	15	15	10½ x 42	30	30	5¾	5	29	27	29	54	48
99	60	17 5	16	17	11½ x 46	30	30	5¾	5	29	27	30	60	54
130	66	17 6	16	18	12½ x 52	36	36	5¾	6	31	29	30	66	60
171	72	19 7	18	19	13½ x 58	36	36	5¾	6	31	29	33	72	66
205	78	19 8	18	20	14 x 66	42	42	5¾	6	31	29	33	78	72
249	84	21 10	20	22	15½ x 68	42	42	5¾	7	32	30	33	84	78
315	90	21 11	20	23	17½ x 78	42	48	5¾	7	32	30	36	90	84
355	96	22 0	20	24	18½ x 82	48	48	5¾	7	32	30	36	96	90

Horsepower	Brick Setting: Thickness of Inside Walls at Bottom	Thickness of two Side Walls with 2-Inch Air Space at Bottom	Thickness of Front Wall	Length of Brick Setting	Width of Brick Setting	Height of Walls from Floor Line	Floor Line to Underside of Boiler at Front	Floor Line to Underside of Boiler at Rear	Floor Line to Top of Dome	Top of Bridge Wall to Underside of Boiler	Space in Rear between Boiler and Wall	Distance from Center to Center of Boilers in Battery	Width of Center Wall at Floor Line
	M	N	O	P	Q	R	S	T	U	V	W		
	In.	In.	In.	Ft. In.	Ft. In.	Ft. In.	In.	In.	Ft. In.	In.	In.	Ft. In.	In.
16	16	26	9	11 7	6 10	7 0	51	50	8 11	10	20	4 6	26
29	16	26	9	13 7	7 4	7 7	53	52	9 11	10	20	5 2	26
48	16	26	9	15 7	7 10	8 0	56	55	11 0	10	20	5 8	26
78	16	26	9	18 9	8 [illegible]	8 6	58	57	11 10	12	22	6 6	30
99	20	30	9	19 11	9 6	8 10	59	58	12 5	12	24	7 0	30
130	20	30	9	20 3	10 0	9 8	61	60	13 7	14	28	7 8	32
171	20	30	9	22 5	10 6	10 1	64	63	14 4	14	30	8 2	32
205	20	30	9	23 5	11 0	10 6	64	63	15 4	14	30	8 8	32
249	20	30	9	24 5	11 6	11 0	65	64	15 11	14	30	9 2	32
315	20	80	9	24 5	12 0	11 6	68	67	17 2	14	30	9 10	34
355	20	30	9	24 5	12 6	11 11	68	67	17 8	14	30	10 4	34

Horsepower	Miscellaneous: Number of Common Brick required above Floor Line for Single Boiler	Number of Fire-Brick required, Furnace Lined to back of Bridge Wall	Additional Number of Common Brick per Foot of Boiler Length	Number of Common Brick for Each Boiler set in Battery after the First	Additional Number of Common Brick for Each Boiler set in Battery after the First, per Foot of Boiler Length	Flue Area Required for Each Boiler	Diameter of Stack Required for Each Boiler	Height of Stack Above Grate	Approximate Weight of Bare Boiler	Additional Weight of Bare Boiler for Each Foot of Tube Length	Approximate Weight of Boiler Complete with All Castings and Fittings
						Sq. Ft.	In.	Ft.	Lbs.	Lbs.	Lbs.
16	6,250	650	600	4,000	300	1.5	16	50	3,100	350	5,500
29	8,200	725	630	5,500	345	2.0	20	60	4,600	400	7,300
48	10,700	850	685	7,000	350	2.5	22	60	6,600	475	10,200
78	17,680	1,000	725	11,200	385	3.75	26	70	8,600	525	13,000
99	19,000	1,200	780	12,000	400	4.75	30	70	12,000	600	16,700
130	21,550	1,400	820	13,500	430	5.8	33	70	14,800	815	21,000
171	23,500	1,600	860	15,000	470	6.5	36	80	19,700	980	27,000
205	24,500	1,750	925	15,800	520	7.5	38	80	23,000	1,145	31,500
249	28,500	1,850	990	18,000	570	9.0	40	80	29,000	1,315	39,000
315	29,900	1,900	1,040	18,500	600	10.5	44	90	37,000	1,700	46,500
355	32,150	2,020	1,100	21,900	650	12.0	48	90	42,000	1,935	53,000

dividing wall between boilers; where this is the case too great care cannot be exercised to keep such columns from being overheated. There should be at least 13 ins. of brickwork between the column and the fire and a 2-in. air space around the column, with free ventilation in this space. To accomplish this, air should be admitted near the bottom of the column through an open duct not less than 10 ins. square, and with free opening at the top. These requirements, where a column 8 ins. in diameter is used, mean that the minimum wall thickness between the boilers at the grate level must be 38 ins.

Floor Space for Reciprocating Engines. H. A. Lardner (Transactions American Institute of Electrical Engineers, April, 1903) states that the floor space required is affected more by the design than the size of the unit. Vertical space has proved cheaper than floor space. The floor space required per h. p. at 3 central stations in New York is as follows:

	Units, h.-p.	Sq. ft. per h.-p.
Edison station	5,500	.33
Metropolitan station	4,500	.50
Manhattan Station	8,000	.55

Cost of Space for Different Types of Boilers. C. R. D. Meier (Engineering and Contracting, Oct. 22, 1913) in comparing the space occupied, per rated horse power, by the various types of boilers, shows the cost of floor space per boiler horse power. Taking the cost per sq. ft. as $10, for example, we note that the cost per boiler horse power with Type A is $7.84; with Type A with alleys, $8 96; with Type C, $11.50; with Type B, $13.50, and with Type D, $13.32, Type A being the horizontal pass type boiler; B, vertical baffle, horizontal water tube boilers, No. 1 with inclined headers, No. 2 with vertical headers, and No. 3 with a cross-drum and vertical headers, this reducing the head room; C, inclined water tube boilers, No. 1, being a standard setting and No. 2 arranged with A-shaped furnace; D, horizontal boiler with steel water legs instead of sectional headers, as in Type B. It has 4-in. tubes, vertical baffles, and a tube spacing similar to Type A, so that the space occupied is approximately the same as for Type B.

Money Value of Head Room. The different head room requirements with the boilers under consideration are given below.

COMPARATIVE HEIGHTS AND COSTS FOR DIFFERENT TYPES OF BOILERS

Type of boiler	Ht., ft.	Add'l. ht. comp'd. to A	Ditto, %	Add'l. cost of boiler plant bldg., acc't. greater ht. per hp.
A	22.00	0	0	0.00
B_1	26.25	4.25	19.3	0.24
B_2	"	"	"	"
B_3	23.60	1.60	6.8	0.09
C_1	30.00	8.00	36.4	0.46
C_2	33.50	11.50	52.3	0.65
D	24.00	2.00	8.7	0.11

It now remains to determine the money value of head room so that these costs may be properly combined with the floor space figures.

We may assume $5 per boiler h. p. as an average cost of a boiler plant building alone, as corresponding to the average value of $10 per sq. ft. for the cost of building foundations and real estate. It is unnecessary to analyze the money value of head room for a range of values of boiler plants from the minimum to the maximum, because this item is less important than floor space.

Obviously, the height of the boiler plant building will not affect the cost of real estate and, and for all practical purposes, the cost of foundations. Furthermore, increasing the height of the boiler room does not increase its cost so much in proportion as does an increase in the plan area of the building. The reason for this is that the side walls and columns may be increased in height at a less cost than the roof construction. We shall therefore assume that doubling the height of the building increases its cost only 50%, whereas if the cubical contents were increased the same amount by making the floor area double, the cost would be increased 100%. In the second place, an increase of a certain percentage in the height of a boiler does not increase the height of the boiler room by the same amount; the clearance above the boilers remains practically the same in any case. We shall therefore make the further assumption that an increase in the height of a boiler of 100%, instead of increasing the height of the boiler room by 100%, increases that dimension only 50%.

Total Saving per Boiler Horse Power. Table XXIV shows the additional costs, due to increased floor space and head room, of the different types of boiler as compared with Type A without 6-ft. alleys between batteries. These costs are evaluated on a basis of $10 per sq. ft., which is a fair average. The costs due to greater heights are taken from the calculations above, which were made on a basis of the cost of a boiler plant building of $5 per h. p. which would correspond to $10 per sq. ft. for buildings, real estate and foundations.

It is seen that, compared with Type A without alleys (for hand firing and a few types of stokers), the additional cost for the various other types of boilers ranges from $3.49 to $5.90 per h. p. As compared to Type A with alleys (the general condition for stokers), the additional cost ranges from $2.37 to $4.78 per boiler h. p. If, instead of considering the one basis of $10 per sq. ft., we consider the upper and lower limits of $22 and $3.50, it is evident that the saving in space occupied, with the Type A boiler, as compared to the various other types, is worth from $1 to $10 per boiler h. p.

Money Value of Floor Space. The money value of space saved will depend on:

(1) The cost of real estate.
(2) The cost of foundations.
(3) The cost of the power plant building.

Power plants, factories and industrial plants are generally lo-

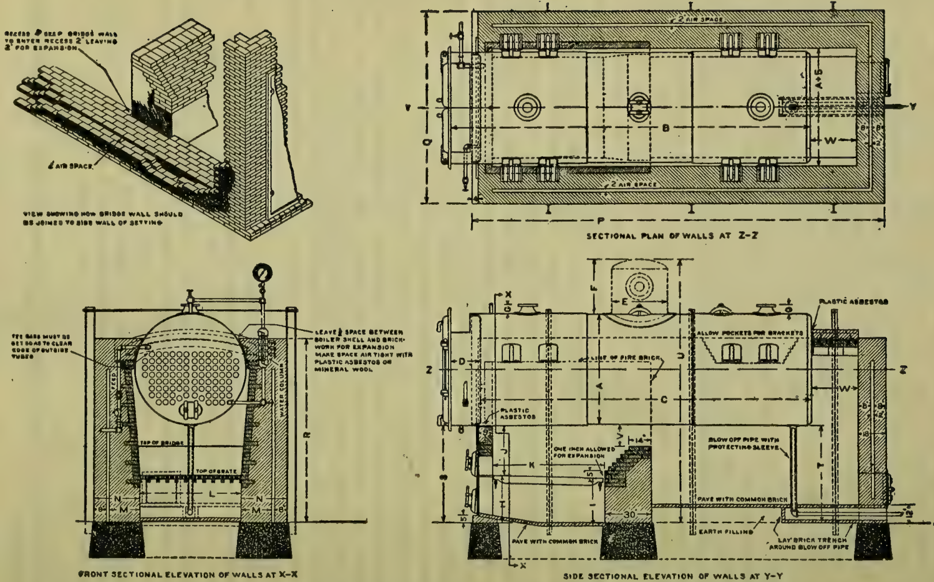


Fig. 6. Setting plan of horizontal return tubular boiler set with overhanging front and boiler set on brackets.

cated where real estate is cheap, but nevertheless in many cases the cost of the site will be 50 to 100% of the cost of the building itself. (Power, Jan. 26, 1909, p. 219.)

The cost of the generator station building, and of the land occupied, of the Edison Electric Illuminating Co. of Brooklyn, is $29 per kw. (Engineering and Contracting, April 6, 1910), and as the cost of the building probably lies between $10 and $20, the land and the building are about equally expensive.

As against this upper extreme, we have such plants as factories in outlying districts of small towns where the cost of real estate might be as low as 25 cts. per sq. ft. Between these values lie the factories, breweries, mills and similar plants, in medium-sized

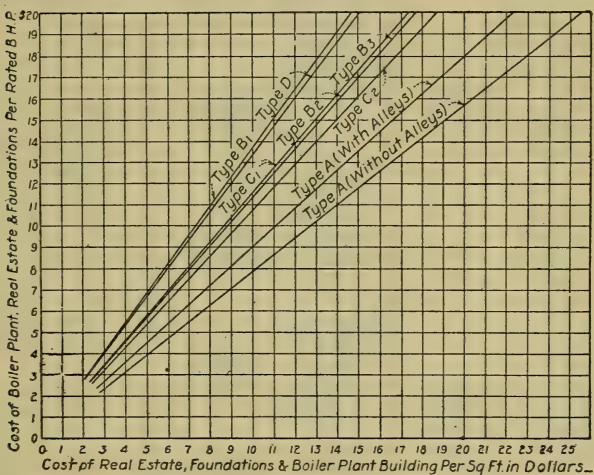


Fig. 7. Relation of cost per sq. ft. of floor space, to cost per boiler hp. of various types of boilers.

cities. We must also consider isolated plants in cities and shall assume the following limits for the value of real estate: Real estate, 25 cts. to $10 per sq. ft.

In a paper on "Steam Power Plants," by O. S. Lyford and R. W. Stovel, in the January, 1911, Proceedings of the Engineers' Society of Western Pennsylvania, it is pointed out that foundation costs range from $1.25 to $4 per sq. ft. of building plan area, depending upon the character of the soil. The lower figure covers simple concrete footings for good bearing soil, while the higher figure covers locations where piling or rock excavation is required. We shall assume the same figures, viz.: Foundations, $1.25 to $4 per sq. ft.

The same paper states that power plant buildings cost $4 to

TABLE XXIV. ADDITIONAL COSTS OF VARIOUS TYPES OF BOILERS AS COMPARED WITH TYPE A, WITHOUT ALLEYS

Type of boiler.	Add'l cost per boiler h.-p., on basis of $10 per sq. ft. of plan area. Compared to Type A without alleys.	Compared to Type A with alleys.	Add'l cost per h.-p. due to greater head room	Total add'l cost per boiler h.-p. for average conditions of cost of real estate, foundations and buildings of $10 per sq. ft., and add'l height. Compared to Type A without alleys.	Compared to Type A with alleys.
Type A with alleys	$1.12	$0.00	$0.00	$1.12	$0.00
Type B	3.50	2.38	0.24	3.74	2.62
Type C	3.66	2.54	0.46	4.12	3.00
Type D	5.48	4.36	0.11	5.59	4.47

TABLE XXV. COMPARATIVE AREAS REQUIRED FOR DIFFERENT TYPES OF BOILERS

Type of boiler	Area required for boilers only (sq. ft.)	Area per rated h.-p. for boilers only (sq. ft.).	Total area of boiler room per rated h. p. (sq. ft.).	Add'l space per h.-p. compared to Type A without alleys.		Add'l space per h.-p. compared to Type A with alleys.	
				Sq. ft.	Pct.	Sq. ft.	Pct.
Type A without alleys	2,813.6	0.392	0.784	00	00	....	...
Type A with three alleys..	3,233.9	0.448	0.896	0.112	14.6	00	00
Type B	4,081.7	0.567	1.134	0.350	44.6	0.238	26.5
Type C	4,147.7	0.575	1.150	0.366	46.7	0.254	28.3
Type D	4,799.9	0.666	1.332	0.548	70.0	0.436	48.5

TABLE XXVI. COMPARATIVE HEIGHTS AND COSTS FOR DIFFERENT TYPES OF BOILERS

Type of boiler	Height, in ft.	Add'l height compared to Type A, in ft.	Per cent. additional height compared to Type A	Add'l. cost of building on account of greater height, per h.-p.
Type A	22.00	0	0	$0.00
Type B	26.25	4.25	19.3	0.24
Type C	30.0	8.00	36.4	0.46
Type D	24.0	2.0	8.7	0.11

$12 per kw. and that the plan area will average from 0.8 to 1.5 sq. ft. per kw., giving a cost per sq. ft. of from $2.70 to $15.

In Power, of Aug. 22, 1911, p. 274, A. E. Dixon cites a case of a power plant building in the Middle West of 1,600 kw. where the building cost was $2.35 per sq. ft. The author also states that in many of the larger steam plants the cost of the building per sq. ft. is much higher than the figure for this plant, ranging from $5 to $10 without foundations.

In Data Chicago, for September, 1910, is given a chart with 6 cases of power plant buildings varying in plan area from about

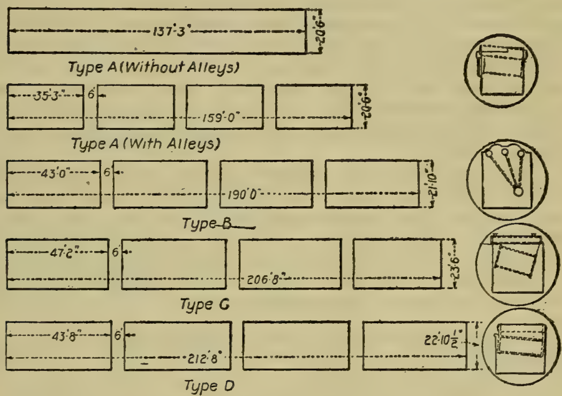


Fig. 8. Required floor space for eight boilers of 9,000 sq. ft. heating surface, each for different types of water tube boilers.

3,000 to 30,000 sq. ft., which ranged in cost from $2 to $4 per sq. ft.

On the basis of the foregoing, we shall assume: Cost of buildings, $2 to $8 per sq. ft. of plan area. Grouping the three items of real estate, foundation and power plant building, we have the following:

Real estate, cost per sq. ft.	$0.25 to $10
Foundations, cost per sq. ft.	1.25 to 4
Power plant buildings, cost per sq. ft.	2.00 to 8
Total cost per sq. ft.	$3.50 to $22

The chart of Fig. 7 is drawn with the above limits of cost per sq. ft. of space.

Number of Brick Required for 507 h. p. Boiler. The brick required above the floor line in setting a 507 h. p. Stirling boiler in a power house in Washington were as follows:

	Number required
Arch fire brick:	
High grade, standard size	476
High grade, wedge shape, 2½ by 2 by 4½ by 9 ins.	532
Wall Fire Brick:	
High grade, standard size	3,846
Second grade, standard size	2,398
Third grade, standard size	2,758
Miscellaneous:	
Red brick	23.755
Fire tile, 12 by 2 by 12 ins.	279

Cost of Erecting Harrington Automatic Stoker Under a Return Tubular Boiler. C. L. Samson (Engineering and Contracting, Aug. 16, 1911) gives the cost of tearing out the old cast iron front, furnace iron work, bridge wall and all fire brick lining in front of the bridge wall of a 72-in. and 18-ft. horizontal return tubular boiler, and the erection of a Harrington automatic stoker in place, rebuilding the bridge wall and relining the furnace from the bridge wall to the front.

The floor line of the old furnace was too low to permit the use of the ash drag furnished with stoker. This necessitated cutting out the concrete floor and digging pit 8 × 9 ft. by 2 ft. 6 ins. deep at the front of the furnace. The material excavated consisted of 6 ins. of concrete floor and 2 ft. of shelly rock. All excavating was done with sledge and wedges. The itemized costs of the various parts of the work were as follows:

Cost of tearing out old boiler front, 13 hrs. at $0.25	$ 3.25
Excavation for ash pit, 74½ hrs. at $0.25	18.62
Centering for arches, 18 hrs. at $0.30	5.40
Forms for concrete work, 7 hrs. at $0.30	2.10
Door over ash pit, ½ hr. at $0.25	.13
Brick work, 165½ hrs. at $0.25, 55 hrs. at $0.21	52.93
Erecting iron work, 59 hrs. at $0.25, ⅓ hr. at $0.30	14.90
Steam piping to stoker engine, 21 hrs. at $0.25	5.25
Sorting and handling old firebrick, 25 hrs. at $0.25	6.25
Concrete work, 15 hrs. at $0.25	3.75
Total cost of labor	$112.58

The above costs do not include superintendence and material.

In another case the work included erecting stokers, rebuilding the bridge wall and relining the furnace from the bridge wall to the front. The floor of the old furnaces was so low as to necessitate cutting out the floor and excavating a pit; the floor being concrete and the excavation being rock and the work being done with sledge and wedges. The cost of installing the first stoker as itemized in article mentioned above was $12.58. The same gang put in the remaining three stokers. It will be noted that the cost gradually decreased with the successive installations. The following were the costs of labor for stokers 2, 3 and 4:

SECOND STOKER

Excavation, 82 hrs. at 25 cts.	$ 20.50
Tearing out old fronts, 10 hrs. at 25 cts.	2.50

Forms for concrete, 7½ hrs. at 25 cts.	$ 1.88	4.28
Forms for concrete, 2 hrs. at 30 cts.	2.40	
Centering for arches, 2½ hrs. at 30 cts.	.75	3.63
Centering for arches, 11½ hrs. at 25 cts.	2.88	
Concrete work, 32½ hrs. at 25 cts.		8.13
Unloading stoker, 4½ hrs. at 25 cts.		1.13
Unloading sand, 2 hrs. at 25 cts.		.50
Unloading firebrick, 15⅔ hrs. at 25 cts.		3.92
Brickwork, 36 hrs. at 22 cts.	7.92	37.67
Brickwork, 119 hrs. at 25 cts.	29.75	
Erecting iron work, 44 hrs. at 25 cts.	11.00	19.10
Erecting iron work, 27 hrs. at 30 cts.	8.10	
Teaming		2.50
Shafting, 12 hrs. at 30 cts.	3.60	4.98
Shafting, 5½ hrs. at 25 cts.	1.38	
Total labor		$108.84

Third Stoker

Excavation, 89 hrs. at 25 cts.		$ 22.25
Tearing out old front, 10 hrs. at 25 cts.		2.50
Forms for concrete, 16 hrs. at 30 cts.	$ 4.80	5.30
Forms for concrete, 2 hrs. at 25 cts.	.50	
Centering for arches, 7 hrs. at 25 cts.		1.75
Concrete work, 20 hrs. at 25 cts.	5.00	5.84
Concrete work, 4 hrs. at 21 cts.	.84	
Unloading stoker, 4½ hrs. at 25 cts.		1.13
Unloading sand, 2 hrs. at 25 cts.		.50
Unloading firebrick, 15⅔ hrs. at 25 cts.		3.92
Brickwork, 98 hrs. at 25 cts.	24.50	33.53
Brickwork, 43 hrs. at 21 cts.	9.03	
Erecting iron work, 77 hrs. at 25 cts.	19.25	21.98
Erecting iron work, 13 hrs. at 21 cts.	2.73	
Shafting, 4 hrs. at 30 cts.		1.20
Teaming		2.50
Total labor		$102.40

Fourth Stoker

Excavation, 101½ hrs. at 25 cts.	$25.38	$26.85
Excavation, 7 hrs. at 21 cts.	1.47	
Tearing out old front, 12 hrs. at 25 cts.		3.00
Forms for concrete, 2 hrs. at 30 cts.	.60	2.10
Forms for concrete, 6 hrs. at 25 cts.	1.50	
Centering for arches, 5 hrs. at 21 cts.		1.05
Concrete work, 26½ hrs. at 25 cts.		6.62
Unloading stoker, 4½ hrs. at 25 cts.		1.13
Unloading sand, 2 hrs. at 25 cts.		.50
Unloading firebrick, 15⅔ hrs. at 25 cts.		3.92
Brickwork, 98 hrs. at 25 cts.	14.50	21.34
Brickwork, 32½ hrs. at 21 cts.	6.84	
Erecting iron work, 1 hr. at 30 cts.	.30	14.55
Erecting iron work, 57 hrs. at 25 cts.	14.25	
Shafting, 3 hrs. at 30 cts.	.90	1.65
Shafting, 3 hrs. at 25 cts.	.75	
Teaming		2.50
Platform for ash pit, 3 hrs. at 25 cts.		.75
Cleaning up boiler room, 5 hrs. at 25 cts.		1.25
Total		$87.21

Cost of Setting Two 200 h. p. Boilers at the Bush Terminal, Brooklyn, N. Y. The work was accomplished in bad weather.

Labor	$ 449.83

Material:

38,360 red brick at $12 per M.	$ 400.00
4,500 fire brick at $32 per M. / 75 Bull nose fire brick at $32 per M.	141.40
36 bbls. of lime at $1	36.00
12 lbs. of Rosendale cement at $2	24.00
29 yds. sand at $1.25	34.25
11 bbls. fire clay at $3	33.00
	$ 670.65
Total cost of setting boiler	$1,219.83

Cost of Two Engine Foundations at the Corliss Surprise Store, 8th Avenue, New York. A 1:4:6 mixture of concrete was used.

Labor:	
27½ days at $2	$ 55.00
Material Used:	
21 bbls. cement at $2	42.00
8 yds. sand at $1.75	14.00
13 yds. stone at $3	39.00
Material Hauled Away:	
18 yds. earth at $1.25	22.50
Total cost of foundations	$172.50
Excavation, cu. yds.	17
Concrete, cu. yds.	17
Cost of foundation per cu. yd.	$10.10

Cost of Moving and Erecting a 400 h. p. Corliss Engine and 500 k. w. Generator. In describing the moving and erection of a Corliss engine and generator C. L. Samson (Engineering and Contracting, Aug. 16, 1911) states that the engine and generator came knocked down on flat cars and were hauled 1½ miles over paved streets on a heavy truck, especially designed for hauling heavy loads. The heaviest piece weighed 15 tons. It so chanced that the streets were slightly down grade for the entire distance, so that four horses were sufficient to draw the heaviest parts. The most of the parts, however, were drawn by a 2-horse team.

The installation was in an old building and the floor was not strong enough to support the weight of the heavier parts. Shores were accordingly set under floor sills and joists at about 36-in. centers to strengthen the floor.

A gin pole with a 4-sheave rope block and a hand power double-geared winch was used in taking off the top half of the generator field ring and for lowering the bottom half of the flywheel into the wheelpit. All other parts were placed on skids, rolled into position and lowered with jacks.

A house mover furnished his services with the truck, one team, blocking and the necessary jacks and rigging for $10 per day. The man sent by the engine company supervised the erection of the engine and the company furnishing the generator sent a man to supervise the erection of the electrical equipment.

Charges for moving the generator are high, due to a truck breaking down under load with considerable delay in transferring the load.

The charges for erection on both engine and generator are high, due to delay in arrival of certain parts that failed to come with the rest of the machinery. The charges for installation and covering of steam and exhaust piping are high due to the fact that they were laid under the floor where only about 18 ins. working space was available. Further, two concrete foundation walls had to be pierced. The steam line was about 18 ft. long and the exhaust line was about 45 ft. long. Both steam and exhaust lines were 8 ins. and flanged pipe and fittings were used. Aside from pipe and fittings, little material was used and the charges below given are for labor only.

The weight of the engine was 41 tons and the weight of the generator was 20 tons. The switchboard, transformers and fittings weighed about 5 tons. The itemized costs of labor were as follows:

Cost of shoring up engine room floor, 43½ hrs. at $0.30	$ 13.05
Cutting walls for steam piping, 59½ hrs. at $0.25	14.88
Covering steam piping:	
20 hrs. at $0.30	6.00
91 hrs. at $0.25	22.75
Total	$ 28.75
Piping for oiling system:	
8 hrs. at $0.30	$ 2.40
118 hrs. at $0.25	29.50
Total	$ 31.90
Moving engine:	
23 hrs. at $0.30	$ 6.90
136½ hrs. at $0.25	34.12
House mover	34.50
Extra men	6.00
Total	$ 81.52
Setting up engine:	
137 hrs. at $0.30	$ 41.10
343 hrs. at $0.25	85.75
House mover	56.00
Erector	286.15
Total	$469.00
Moving generator:	
43½ hrs. at $0.30	$ 13.05
58½ hrs. at $0.25	14.62
House mover	42.50
Extra team	4.00
Total	$ 74.17
Setting up generator:	
4 hrs. at $0.30	$ 1.20
102 hrs. at $0.25	25.50
House mover	38.00
Erector	190.00
Total	$254.70
Total cost of labor for moving and erecting engine and generator	$967.97

Cost of Wrecking a Plant after a Fire. Wilfred Twinch (Power, Oct., 1907) gives the following account of wrecking the Minnesota Sugar Company's plant, at St. Louis Park, Minn., after it was burned down. The plant cost $400,000. The main building and warehouses were of enamel brick, one end of the plant being of mill construction, two stories high, and the other end part steel and three stories high. Some of the heaviest machinery was supported by iron columns. The floors were wood. After the insurance was adjusted the plant was turned over to the engineer to wreck. He was instructed to save everything worth saving, to sell the scrap and to clear the ground. There were four cast-iron evaporators, built-up structures, 20 ft. long, 8 ft. wide and 8 ft. high, with their backs broken. There were eight wrought-iron crystallizers weighing 20 tons each, and there were steel storage tanks and pipe lines galore. Altogether there was sufficient salvage to preclude the use of dynamite.

The engineer had had no previous experience in wrecking, so he concluded that scrapmen could do it more cheaply. These gentlemen were found to be banded together and very difficult to deal with. At first the best proposition they would offer was to pay us $2.40 a ton for the wreck, they to clear the ground, leaving us everything we wished to retain. Finally competition got pretty sharp, and we closed a contract with one fellow to clear the ground and pay $6.75 a ton for all wrought- and cast-iron scrap, 12½ cts. per pound for copper scrap, 4 cts. for brass, and $3 per thousand for whole brick. Fortunately we had a lawyer to draw up a contract which contained a penalty clause for not finishing the job within 60 days.

These wreckers were specialists, competent to handle such a proposition. Incidentally we learned that it is best to consider all machinery that has been in the heat of a fire as scrap, only scrap, and that cast-iron columns go through fire better than builtup columns, because they are capable of withstanding more heat.

The wreckers first extended the railroad track into the wreck and procured two gondola cars, then removing by hand and team such as they could, they put the cast-iron scrap into one car and the wrought-iron into the other. Next they installed a guy derrick with a 60-ft. mast, with 18 × 18-in. base and a 70-ft. boom; also a double-cylinder, 7 × 10-in. hoisting engine. Care was taken in locating the derrick so it would need shifting only three times, as each move cost $50 to $60 in labor.

The big cast-iron evaporators, condensers, vacuum pans, etc., were broken up by dropping a big ball upon them from the top of the derrick. All wrought-iron work and the steel structures were cut up with cold chisels and sledge hammers, piece by piece. To show that the workmen were not amateurs, the pipe work was unscrewed where necessary, or the flanges were broken with sledge hammers.

Cost of Wrecking the Plant. The market price for wrought- and cast-iron scrap, mixed, was $10 per ton, f.o.b. cars; the contract price was $6.75 per ton on the ground, so the contractor

evidently allowed $3.25 a ton for wrecking and loading. Following is the actual cost as checked up daily by the company's engineer:

Labor (excluding derrick gang) 4500 hours at 22½ cents...	$1,012
Supervision, 2 men for two months, at $75	300
Team, 10 days at $4	40
Setting derrick	60
Derrick, 60 days at $12 a day (4 men)	720
Derrick repair	50
Loading derrick	50
Tools (say)	30
	$2,262

There was 990 tons of scrap iron shipped, so the actual cost of wrecking and loading was $2.28 per ton.

Installation Costs of Miscellaneous Equipment. Table XXVIII gives *actual* costs of installing power plant equipment and is largely taken from accounting records, in connection with recent appraisals (prior to the war).

TABLE XXVIII. INSTALLATION COSTS

Description	Weight, lb.	Labor	Misc. material	Total	Cost per ton
2–18,000 hp. turbines	611,400	$9,848	$2,440	$12,288	$40.20
1–10,000 hp. turbine	169,000	3,973	924	4,897	57.90
2– 500 hp. impulse wheels	19,200	1,357	1,051	2,408	25.10
1– 5,000 hp. turbine and governor	143,900	1,288	209	1,497	20.80
1– 1,000 hp. turbine	148,000	825	36	851	11.50
2–10,000 kw. generators	470,000	3,719	1,332	5,051	21.50
2– 225 kw. exciters	48,000	590	362	952	39.50
1– 7,000 kw. generator	199,100	2,285	1,190	3,475	35.00
2– 1,500 kw. motor generators	309,700	1,566	372	1,938	12.50
1– 500 kw. motor generator	41,115	347	7	354	17.30
1– 1,250 kw. generator	32,500	235	62	297	18.30
1– 3,750 kw. generator	107,360	392	17	409	7.80
1– 1,400 kw. generator	66,700	401	21	422	12.60
7–3,333 kw. transformers	245,000	1,573	340	1,913	15.60
4–1,000 kw. transformers	78,000	....	....	507	13.00
1–1,000 kw. transformer	33,000	110	33	143	8.70
3– 200 kw. transformers	28,500	262	10	272	19.20
3–1,500 kw. transformers	55,500	1,138	152	1,290	46.50
3–1,000 kw. transformers	57,600	752	237	989	34.30
3– 200 kw. transformers	28,300	765	22	787	55.80
1–2,200 kw. transformers	66,200	....	....	771	23.30
1–60 ton crane	114,000	1,708	140	1,848	32.40
1–50 ton crane	77,000	1,004	136	1,140	29.60
1–25 ton crane	24,000	290	....	290	24.20
1–30 ton crane	42,000	....	....	417	19.80
1–10 ton crane	11,500	....	....	140	24.30

How a Machine Foundation in a Substation Was Removed by Dynamite. (Electrical World, March 11, 1916.) A booster set in the Kolmar Avenue (Chicago) substation of the Commonwealth Edison Company has been removed to make room for a new

2000-kw. synchronous converter. A part of the reconstruction work incident to the change consisted in removing the booster foundation, which was built in a solid concrete block 12 ft. wide by 15 ft. long by 5 ft. high. To remove this monolithic block by manual labor would have taken 8 men a week working 8 hrs. a day with points and sledges.

A quicker and more efficacious method, however, was adopted. Working with air hammer and drills, a workman made 25 1.5-in. holes varying in depth from 12 ins. to 30 ins. in the concrete. Two licensed dynamiters, whose services had been secured from the Chicago surface Lines, then set and ignited 14 dynamite blasts, which completely removed the old foundation. The man who drilled the holes worked from 2 to 11 P. M on his part of the job. The dynamiters worked from 1.30 A. M. till 4.30 A. M. the following morning, firing the first blast at 1.30 A. M. and the last at 4.21 A. M. While the dynamiters were at work the two converters at the substation were shut down. This experience with dynamiting has led the company's engineers to believe that machine foundations inside of buildings can be more safely, speedily and economically removed by men who thoroughly understand dynamiting than by laborers with sledges and points.

CHAPTER VI

FUEL AND COAL HANDLING

Easy Calculation of Steam Coal Required by Power Plants. R. E. Horton in Engineering News, March 11, 1915, gives the data in Table I for use in calculating the cost of coal required by actual or hypothetical steam plants under comparison with proposed hydraulic stations.

Computations were carried through and tabulated for the yearly coal consumption in tons at a rate of 1 lb. per h.p.-hr. under various conditions. Now it is only necessary to ascertain or estimate and combine (1) the simplest unit coal consumption (per h.p.-hr., including allowance for shrinkage and waste if any); (2) the average h.p. in use when running; (3) the allowance for banking; (4) the hrs. use per day, and days per year.

TABLE I. FACTORS FOR CALCULATING AMOUNT OF STEAM COAL REQUIRED PER HORSEPOWER-YEAR

	Gross tons, 2,240 lbs.		Net tons, 2,000 lbs.	
Method of operation	310 days	365 days	310 days	365 days
10 hrs. per day, no banking	1.38	1.63	1.55	1.83
10 hrs. per day, plus ⅓ for banking.	1.84	2.17	2.07	2.43
12 hrs. per day, no banking	1.65	1.96	1.86	2.19
12 hrs. per day, plus ⅓ for banking	2.21	2.61	2.48	2.92
24 hrs. per day, no banking........	3.32	3.91	3.72	4.38

For example: A plant runs 10 hrs. per day and 310 days per year, produces 500 h.p. average, uses 2½ lbs. per h.p.-hr. of steam coal, has ⅓ allowance for banking; coal costs $3.50 per gross ton. From the table, the proper unit consumption per h.p.-year is 1.84 gross tons. Then,

$$2.5 \times 1.84 \times 500 \times \$3.50 = \$7{,}735 \text{ annual cost.}$$

Sometimes it is necessary to know the tons of ash that will have to be disposed of each year; then it is necessary only to substitute the decimal percentage of ash in the coal for the price per ton. For 15% ash the foregoing case shows

$$2.5 \times 1.84 \times 500 \times 0.15 = 345 \text{ gross tons.}$$

Theoretical Mechanical Equivalent, in H. P. Hours, of Heat Energy Contained in Common Fuels. Fig. 1 shows the equivalent theoretical energy contained in the ordinary units of measure of

common fuels. The chart has been prepared by taking accepted standards for the heat content per pound of fuels such as wood, coal anthracite and bituminous, alcohol, petroleum, etc., taking 1 B. t. u. equal to 778 ft.-lbs. and 1 h.p. equal to 2,545 B. t. u. per hour.

Knowing the thermodynamic efficiency of any combination of boiler and engine and the heating value of any fuel in B. t. u.'s the amount of fuel required to operate the plant can readily be

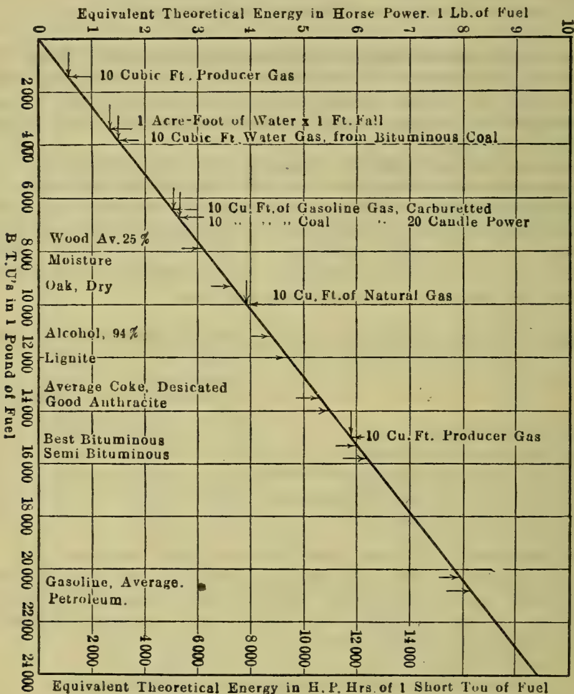


Fig. 1. Theoretical energy contained in lbs. of fuel for heating values up to 24,000 B.t.u. per lb., a B.t.u. being equal to 778 ft.-lbs.

estimated from the chart. Or, knowing the heating value of a fuel, and the amount of fuel required to produce a mechanical h.p., the thermodynamic efficiency of the plant can be determined.

Thus, a plant operating with an average boiler efficiency of 70%, a heat loss from radiation of 5% and an efficiency of engine and auxiliaries of 20% has a total net operating efficiency of $70 \times 95 \times 20 = 13.3\%$. If the plant uses coal with a heating value

of 14,000 B. t. u. per lb. 1 ton of fuel would produce $11,000 \times 0.133 = 1,463$ h.p.-hrs. If the plant is required to develop 100 h.p., 8 hrs. per day for 300 days or 240,000 h.p.-hrs. per year there will be required $240,000 \div 1,463 = 164$ tons of fuel.

The Economy to the Consumer Resulting from the Purchase of Coal Under Specifications. The advantage to the consumer arising from the purchase of coal according to specifications was shown clearly by W. O. Collins, vice-president of the Gullock-Henderson Co. of Chicago, in a paper before the Illinois Water Supply Association, printed in Engineering and Contracting, March 27, 1912. The adoption of this phase of the economic operation of pumping and power plants merits the careful consideration of the superintendents of such plants.

The heat value and burning qualities have always been the underlying basis of consideration wherever it has been possible to choose between one or more grades or sizes of coal. We find all sorts of crude methods used in making these decisions and too often we find that a consumer simply knows that one kind of coal seems to burn better than another without really knowing whether or not it is cheaper for him than some other available fuel.

Up until a few years ago the larger consumers employed the boiler test to determine whether or not coal was efficient or up to contract requirements. Selections of coal for contracts were frequently made by this method. Coal contractors were requested to make a shipment of coal representative of the fuel which they proposed to furnish if awarded the contract. Several shipments so received were subjected to burning tests under the boiler and the evaporation per pound of coal and the cost to evaporate 1,000 lbs. of water were determined with more or less accuracy depending on the care with which the tests were made. If coal contractors were wise, as they usually were, extra good coal was often supplied for the test and, generally, extraordinarily high results were recorded.

However, in individual cases this method has been satisfactorily handled and the system is often useful in determining the general grade of fuel best suited for any particular boiler equipment.

On public and political contracts the evaporation method has caused no end of criticism as there are many conditions under the control of the testing engineer and firemen by means of which the results can be controlled at will. Furthermore, even if the tests are honestly and efficiently made, they are useless in the case of a legal fight as it is always possible to show that the conditions of testing are constantly changing to a greater or less extent due to the formation of boiler scale, weather, load and firing requirements.

Along with and following this method of specifying and regulating deliveries a chemical analysis showing the amount of moisture, volatile matter, fixed carbon, ash and heat value was frequently incorporated in the contract together with the guarantee of evaporation obtained by the boiler test method. This was often

a strengthening clause and was many times the basis of making settlement where substitution was clearly evident.

It can not be said that any of these methods were ever universal nor is the new and improved B. t. u. system in universal use. In many cases the fuel which forms from 10 to 25% of the yearly expense, is bought without any supervision whatever, while the much less expensive items, such as steel, pig iron, cement, electrical materials, paper, etc., are often purchased on the most rigid specifications and guarantee.

Following the public demand for efficiency and honest purchasing, the political and public institutions have in many cases been the leaders in scientific methods of purchasing coal. Thus in 1907 the U. S. Government adopted a form of B. t. u. specifications which is now in use by practically all Government departments. The methods used by the Government and the method now in use by other consumers are, generally, based on the same fundamental principle, which is the "delivery of heat units." While there are several different methods of regulating and figuring the value of a delivery, practically all of them consider the analysis of as much importance as the weight of the coal.

The B. t. u. system as applied to public institutions briefly is as follows: Bids for the delivery of fuel are advertised for in the usual way. The advertisement differs little from the common form and often simply states that an amount of coal is desired and that the same will be purchased in accordance with the B. t. u. system, specifications for which may be had by application, etc.

Other specifications differ in detail for different institutions, due to the variations in the coal requirements and business methods of the office. All embrace clauses to cover the following principal points and it will be seen that a specification should cover something more than the mere physical properties of coal.

(1) Conditions under which proposals are to be made must be clearly defined, the bond, certified check, and other general conditions must be explained.

(2) Special requirements such as time and place of delivery, amount of coal required, strike clause (if any), liability of contractor, and clauses covering the purchase on open market must be clearly and specifically drawn. Since a specification is usually the basis of and a part of a contract, it must be legally drawn and fair to both the contractor and consumer, as an unfair contract may not stand the test of the court even though it may have been accepted by the contractor

(3) A general description of the coal wanted should be included in the specifications. This description is usually composed of the chemical analysis limits together with a paragraph relating to size, as follows:

DESCRIPTION OF COAL WANTED

Bituminous lump containing not less than 12,500 B.t.u. per pound of dry coal and not to exceed 14 per cent. of ash dry coal. Lump

coal shall contain all the lumps as mined and shall be so screened as not to contain to exceed 20 per cent. by weight of coal which will pass through a 1¼-in. circular perforated screen.

These limitations are the basis on which future deliveries are to be enforced. Similar chemical and physical restrictions can be drawn to cover other grades and sizes of coal, such as screenings, chestnut anthracite, washed and unwashed nut, etc.

(4) A specification must contain a clause covering and providing for a means of rejection of a shipment should it be far below the limit of the specification as to quality and size.

If coal inferior as to size and quality is kept and burned, it may be accepted and paid for on the basis of deductions made in accordance with the terms of the specifications.

The penalty for excess of fine coal is usually based on a deduction of something like 1½% of the contract price for each 1% excess of fine material as limited above. For example, if lump coal containing not to exceed 20% fines at about $2 per ton was contracted for, and mine run coal containing 32% of fines was actually delivered, the deductions due to fineness would be 1½% of $2 for each 1% of fine coal in excess of the 20% of allowed or a net deduction of 36 cts. per ton. This deduction would be made in addition to any deduction originating from lower heating value.

(5) The real essence of the specification lies in the clause covering methods of payment. This paragraph must literally be bull strong and hog tight.

Believing that each individual contractor should know the analysis and heating value of the coal he is attempting to sell, the responsibility of stating the exact guarantee as to moisture, ash and heat value, is placed upon him. A sheet is provided whereon he may place this detailed information together with the price per ton and the number of heat units which he is willing to guarantee to furnish for one cent.

The testing and payment clause clearly states in words how the B. t. u. for one cent shall be figured and is briefly stated as follows:

Multiply the number of heat units per pound of coal as delivered by two thousand. This gives the number of heat units delivered in every ton. Divide this product by the price of the coal per ton expressed in cents plus an arbitrary correction for ash amounting to one-half the percentage of ash expressed as cents.

Since the anlysis of coal is often expressed on the dry basis, the heat value as delivered must be determined by deducting for the percentage of moisture. Thus the calculation resolves itself to this formula:

$$\frac{\text{B.t.u. dry coal} \times \text{per cent. dry coal (100 less per cent. of moisture)} \times 2.000}{\text{Price per ton in cents} + (0.5 \times \text{per cent. of ash dry coal})}$$

The result of this simple calculation gives the number of heat units for one cent which the bidder proposes to deliver. Samples

are taken from all subsequent deliveries and upon these samples analyses are made and by a converse calculation the value of the coal as delivered is determined accurately.

The specifications state the high and low limits of analysis which will be accepted under any conditions. Coal accepted is paid for on the showing of the analysis.

The method of sampling, chemical analysis and other details of the process are now fairly well standardized and while there are still differences of opinion in minor details, nevertheless it is a fact that they are as well standardized and can be as accurately handled as in the sampling and testing of other materials of commerce, such as iron, steel, cement, etc.

After the preparation and adoption of a scientific and fair specification the personal element again enters and unless the work is honestly and accurately done, without fear and without favor, the system becomes a failure. Although the system has enjoyed a steady growth, still much of the criticism and many of the objections are based entirely on the inefficiency and dishonesty of the testing.

The best of apparatus and the most careful and straightforward work are required. Needless to say the tester must have no affiliations or connections with the coal trade and his efforts must be to maintain the absolute confidence of the coal trade as well as that of the consumer.

In several cases the contractors have continually earned a bonus due to their care in the selection of good coal. There are other cases where they always run behind, due to overbidding. We believe that the bonus should be paid where it is earned and likewise believe in making deductions where the coal is below the guarantee.

Economic Points in the Selection and Purchasing of Coal. An analysis of the coal bids made for a large manufacturer in 1915, made by H. R. Callaway and described in Engineering Magazine, Sept., 1915, is given in the following table, the names of the coals and of the dealers being indicated by index numbers.

Index number	Volatile matter per cent.	Sulphur per cent.	Ash per cent.	B.t.u. dry	Price	Fusing point, deg. F.
1	27.53	1.93	8.32	14,314	$2.80	....
2	23.17	1.70	11.93	13,713	2.85	2,189
3	16.22	1.39	7.52	14,532	2.80	2,774
4	23.20	1.20	10.00	14,135	2.85	2,580
5	16.10	1.69	8.73	14,350	2.90	2,662
6	22.35	.83	9.44	14,178	2.95	....
7	22.75	1.03	8.06	14,307	2.95	2,734
8	17.59	1.81	11.75	13,736	3.00	2,560
9	21.41	1.61	7.42	14,535	2.95	2,938
10	17.28	2.04	10.04	14,160	3.00	2,444
11	22.12	1.49	10.10	14,100	3.00	2,780
12	21.18	.86	7.06	14,587	3.05	2,780
13	18.77	1.34	7.38	14,500	3.05	....
14	20.36	1.33	9.42	14,228	3.05	....
15	17.47	1.56	11.90	13,961	3.10	2,586
16	21.96	2.10	9.36	14,237	3.00	2,460
17	17.65	1.30	7.60	14,565	3.10	2,800

The data as to the character and quality of these coals represented the average of several tests made in connection with independent investigations of the same coal delivered to other plants. The plant in question needed coal running over 20% volatile matter under 1.5% sulphur, under 8.5% ash and at least 2,700 degs. F. for the fusing point of ash. Inspection of the table shows that only Nos. 7 and 12 met these requirements, prices shown in the 6th column. The advantage in favor of No. 7 over No. 12 figured out about $0.04 per ton, No. 12 being of somewhat higher quality on the basis of the ash and the B. t. u. quality.

Mr. Callaway cites a case of a manufacturer who adopted a certain coal seven years ago at $1.60 at the mines and although normally he was running his business in an efficient manner he was continuing to pay $1.60 for this coal in spite of a considerable reduction in the general soft coal market and at that he was not getting the best coal that he could for $1.60 in any market, thus throwing away over $1,000 a year because of a lack of basis of comparison between the coal that he was buying and other coals that he could get.

Specifications for Purchasing Coal. Leo Loeb in Engineering Magazine, March, 1911, quotes the following forms of coal specifications covering large deliveries. The Interborough Rapid Transit Company purchased 360,000 tons of run-of-mine bituminous and dry coal analysis as follows: Carbon, 71%; volatile, 20%; ash, 9%; B. t. u. 14,100 per lb. and sulphur, not over 1.5%. Premiums or deductions on heat value are based on a rate of 1% for each 50 B. t. u. per lb. of coal for each ½% of volatile matter in excess of 21%, 2 cts. per ton was deducted and also 2 cts for each ½% of ash in excess of 9% and a 6-ct. deduction for each ¼% of sulphur in excess of 1½%. Mr. Loeb criticises certain features of this contract as inequitable; first excessive penalties in the case of sulphur and volatile matter, and deductions without corresponding premiums in the case of volatile matter, ash and sulphur, and he objects to the omission of incentive to the dealer to deliver coal low in moisture. The coal is not actually delivered dry but always contains a certain amount of moisture and the B. t. u. in the coal as delivered form the only true basis for potential heat.

The Panama Canal coal for vessels, locomotive, and fuel for dredges and steam shovels, aggregating 650,000 tons per annum, is purchased on a desired quality of 14,600 B. t. u. as received, with acceptance down to 14,350 B. t. u. on deduction of ¼% per 25 B. t. u. or fraction thereof. Coal that analysed below 14,350 B. t. u. and on a dry basis less than 14,750 was penalized 1 cent for each 25 B. t. u. below 15,000 in addition to the above noted penalty. This, in effect, being an ash adjustment, since the coal actually had a value dry of 14,900 B. t. u. Mr. Loeb criticises this as a severe contract, but is justified because although the prices f. o. b. vessels at Norfolk were $2.72½ per long ton in 1908, $2.44 in 1909, and $2.60 in 1910, the total cost distributed to shovels and dredges amounted to $6.50 per ton. He states that the result of this contract was an average delivery for 1908 of 14,547 B. t. u.,

for 1909 there were 14,528 B. t. u. The banner cargo for that year consisted of 5,021 tons containing 2.06% moisture, 3.69% ash, yielding 14,888 B.t.u.

The U. S. Government pays a premium for all coal showing more than 15,000 B. t. u. dry, allowing an ash variation of 2% and penalizing at rates increasing from 2 cts. to 35 cts. per ton from 3% to 9% ash above guarantee. The ash penalties do not change with the price.

Economic Hints on Calorific Tests of Coal. Whereas, the calorific qualities of coal can be determined by laboratory tests in a very convenient and inexpensive manner, the physical properties of the coal, which involve clinkering, packing down on the grates, or adaptability to the mechanical features of automatic stokers, must be determined by actual tests on firing, and these tests depend upon the skill of the fireman, the conscientiousness with which he does his work, and the ability with which he is supervised while the tests are being made. They should be tests under regular running conditions for a considerable period, possibly a week.

Methods of Estimating the Heat Value of Fuel. There are two generally used methods:

Calculations. The formula frequently used is as follows: B. t. u. per lb. of fuel $= C \times 14{,}600 + \left(H - \frac{O}{8}\right) 62{,}000$. Where

C = Decimal part by weight of carbon in the fuel;
H = Decimal part by weight of hydrogen in the fuel;
O = Decimal part by weight of oxygen in the fuel.

In using this formula in determining the value of gas fuels care should be taken not to confuse the weight of gas with its volume and temperature and pressures of gas must be specified. The temperatures most frequently taken are 32 and 60 degs. F., and the pressure, 14.7 lbs., absolute.

Proximate Analysis. The proximate analysis of coal does not give the percentage of total carbon nor the percentage of gases, but it does give the percentage of fixed carbon. The accompanying diagram, Fig. 2, appeared in Power, June 10, 1913, and was constructed from over 300 analyses made by the U. S. Government, representing coal found in 27 different states and territories. It is almost exactly correct for a limited number of cases, reasonably near correct (probably within 3%) for a large number of cases and quite far from correct in a few cases. The curve is most uniformly accurate for coals having combustible matter that contains from 64 to 90% fixed carbon. Where the fixed carbon runs less than 64% the curve may, in a few cases, err as much as 7%.

Application of the Chart. "To estimate the heat value of a coal with a given proximate analysis, add together the percentage of fixed carbon and the percentage of volatile matter in the coal; divide this sum into the percentage of fixed carbon and multiply by 100. This gives the percentage of fixed carbon in the combustible matter. Locate this percentage at the foot of the chart,

extend your pencil straight up until you strike the curve, then extend it to the nearest (left or right) margin in a straight horizontal line and read off the B. t. u. per pound of combustible. Multiply the B. t. u. thus found by the sum of the percentage of fixed carbon and volatile matter in the coal as shown by the proximate anlysis, and the answer, divided by 100, gives the B. t. u. per pound of coal.

"To illustrate with an actual example, assume a coal with this proximate analysis: Moisture, 5.12%; volatile matter, 27.25%; fixed

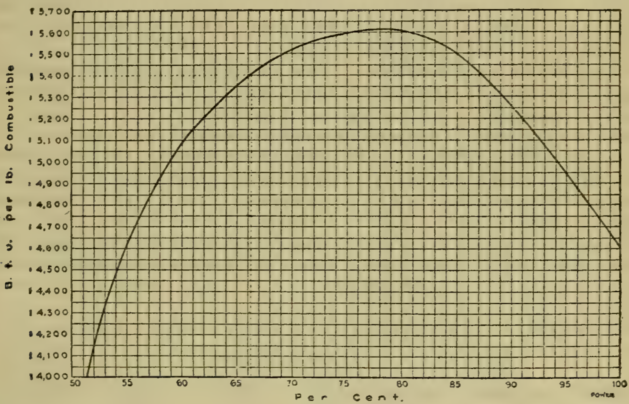


Fig. 2. Diagram for estimating heat value of coal from proximate analysis.

carbon, 53.38%; ash, 14.25%. Adding together the percentage of fixed carbon and the percentage of volatile matter,

$$53.38 + 27.25 = 80.63.$$

Dividing this into the fixed carbon, we have

$$53.38 \div 80.63 = 0.662,$$

which, multiplied by 100, gives 66.2% fixed carbon in the combustible. Referring to the base line of the chart, find the 66% line and judge a point 0.2, or ⅕, of the distance to the next line beyond. Trace an imaginary vertical line (this line is shown dotted on the chart) up from this point to the curve and then horizontally to the left margin. It strikes exactly the 15,400 B. t. u. line. Then, 15,400 B. t. u. may be taken as the heat value of a pound of the combustible matter found.

"Now, if the coal were all combustible and had no moisture nor ash, the heat value per pound of coal would be identical with the heat value per pound of combustible. But only 80.63% of the

coal is combustible. and hence the heat value of a pound of coal is equal to only 80.63% of the heat value of a pound of combustible. Thus, the heat value of the coal is

$$15.100 \times 80.63 \div 100 = 12.417 \text{ B. t. u.''}$$

Relative Value of Anthracite and Semi-Bituminous Coals. The comparison of the relative fuel value of the steam sizes of anthracite semi-bituminous coals shown in Fig. 3 was made by G. B. Gould, vice-president of the Fuel Engineering Company of New York, and was printed in Cost of Power by that company. The average coal quality upon which the chart is based was determined from 8,195 tests of semi-bituminous and 9,885 tests of steam sizes of anthracite made by that company.

The Cost of Coal Analyses. The analysis of coal to determine the calorific value of the fuel costs from a maximum of 2 cts. per ton when the work is done on a small scale to ¼ ct. per ton when the analyses of large shipments are made regularly.

The cost of a calorimeter is from $100 to $150, and the cost for a complete proximate analysis calorific determination in the U. S. Inspection Laboratory is $1.95 per sample in 1911 (Eng. Magazine, March, 1911).

Coal Size and B. t. u. per $1 Cost. The data in Table II given in Isolated Plant, Sept., 1913, show the relative value of various size coals when properly burned.

TABLE II. RELATIVE VALUE OF VARIOUS SIZE COAL

Kind	Pass square hole	Not pass	Specification Ash, pr. ct.	Specification B.t.u.	Approx. price	No. of B.t.u. for $1.00
Broken	4¼	2¾	11	13,200	$6.00	4,400,000
Egg	3	2	11	13,200	6.25	4,220,000
Stove	2½	1¼	12	13,000	6.25	4,000,000
Chestnut ...	1½	¾	12	13,000	6.25	4,000,000
Pea	¾	½	18	12,200	4.25	5,740,000
Buckwheat:						
No. 1	½	¼	19	12,000	3.50	6,860,000
No. 2	¼	3/16	19	11,900	3.15	7,540,000
No. 3	3/16	3/32	19	11,900	2.75	8,600,000

Evaporation Tests as a Check upon Coal Analysis. (After Leo Loeb, Engineering Magazine, March, 1911.)

EVAPORATION TESTS OF TWO COMPETING COALS

Name of coal	Elk Lick.	Orenda.	Orenda.	Elk Lick.
Duration of test, hours..	9	9	9	9
Analysis:				
Moisture	1.80	2.10	2.70	5.80
Ash	9.10	8.20	9.30	8.30
Fixed carbon	68.60	73.70	71.50	65.90
Volatile matter	20.50	16.00	16.50	20.00
B.t.u. as received	14.050	14,070	13,770	13,565
B.t.u. dry coal	14,310	14,370	14,150	14,400
Refuse:				
Combustible matter	22.75	30.10	20.80	21.00
Non-combustible	77.25	69.90	79.20	79.00

Name of coal	Elk Lick.	Orenda.	Orenda.	Elk Lick.
Duration of test hours	9	9	9	9
Per cent. refuse	12.86	9.73	9.74	10.46
Boiler horse power	426.5	421.8	426.8	455.2
Equivalent evaporation per lb. coal as received	10.25	10.51	9.97	9.92
Equivalent evaporation per lb. dry coal	10.44	10.74	10.25	10.52
Equivalent evaporation per lb. combustible	11.98	11.90	11.35	11.75
Efficiency of boiler and grate, per cent	70.45	72.18	69.95	70.55
Contract price, per ton	$3.01	$3.15	$3.15	$3.01
Ash in dry coal, per cent.	7	6	6	7
B.t.u. as received	14,000	14,300	14,300	14,000
Smoke, per cent. black	15.2	1.7	3.62	13.8
Cost of evaporating 1,000 lbs. of steam under observed conditions, cts.	13.08	13.09	13.69	13.12

The two bids considered gave respectively 9.84 and 9.66 cts. per million B. t. u., showing a ratio of 1.018. The first bidder had supplied satisfactory coal for a year; and the second one was known to be slightly inferior from records in the Bureau of Mines. But since there was a possible saving of 1.8%. it was decided to leave the results to evaporation tests on two Babcock & Wilcox boilers of 206 boiler h.p., fitted with mechanical stokers, the results being given in the above table. The result being that the average cost of producing steam with the Elk Lick coal was 13.10 cts. per thousand lbs. and with Orenda 13.39 giving a ratio of 1.021, showing a saving in favor of the first of 2.1% as compared with an expected saving by calculation of 1.8%.

The Weathering of Coal. As the result of some experiments on the weathering of coal conducted at the engineering experiment station of the University of Illinois the following conclusions were reached: (1) Submerged coal does not lose appreciably in heat value. (2) Outdoor exposure results in a loss of heating value varying from 2 to 10%. (3) Dry storage has no advantage over storage in the open except with high sulphur coals, where the distintegrating effect of sulphur in the process of oxidation facilitates the escape of hydrocarbons or the oxidation of the same. (4) In most cases the losses in storage appear to be practically complete at the end of 5 months. From the seventh to the ninth month, the loss is inappreciable.

Variation of Car and Mine Samples of Coal. The following data are from Bulletin 85 of the U. S. Bureau of Mines.

Method of Mine Sampling Followed by Bureau of Mines. The method of collecting mine samples that is practiced by the Bureau of Mines has been described in detail in a previous publication. It involves selecting a representative face of the bed to be sampled; cleaning the face; making a cut across it from roof to floor, and rejecting or including impurities in this cut according to a definite plan as they are included or excluded in mining operations; reducing this gross sample, by crushing and quartering, to about

3 lbs.; and immediately sealing the 3-lb. sample in an airtight container for shipment to the laboratory.

Collection of Car Samples. The carload lots of coal shipped to Pittsburgh for test were sampled by taking definite quantities of coal at regular intervals from a car as it was unloaded, and by reducing to convenient size (about 50 lbs.) the gross sample thus obtained.

Method of Sampling Followed by the United States Geological Survey. In collecting mine samples the Geological Survey follows essentially the same method of sampling as that used by the Bureau of Mines. However, in sampling outcrops and prospect holes or country banks when mining is not in progress, the geologist can not imitate the miner in rejecting or including impurities in the sample, and hence the sample from the cut across the bed includes all partings or binders less than ⅜ in. thick and every concretion or "sulphur ball" having a maximum diameter of less than 2 ins. and a thickness of less than ½ in. All other impurities in the bed are excluded from the sample. Obviously an arbitrary and uniform system of rejecting impurities is necessary for sampling outcrops, prospects, and undeveloped mines.

Relation of Mine Samples to Commercial Shipments. In making statements, on the basis of the analyses of mine samples, in regard to the quality of coal shipped from a mine due allowance must be made for the larger proportion of impurities that may be included in the commercial operation of the mine. It is difficult to take a mine sample in which impurities are rejected in exactly the same manner as is done by the miner. The practice of different miners will vary, especially if rigid inspection at the tipple is not enforced. In some mines, for instance, where the coal bed has friable partings or has a soft, flaky roof or floor, the inclusion of some foreign matter is unavoidable. Hence the analysis of the mine sample usually indicates a better grade of coal, as regards ash content and heating value, than the actual commercial shipments, and for this reason the mine sample should be considered as representing the coal that can only be produced under the most favorable conditions of mining and preparation.

In commercial shipments that are sampled at their destination the moisture content may be either more or less than that in the mine samples, the relative proportions depending on the amount of bed moisture, the size of the coal, and the weather conditions during transit.

Coals containing 5% or more of moisture tend to lose moisture while in transit. Slack coal usually contains more moisture than the mine sample. Low-moisture coals shipped in open cars may gain or lose moisture, depending on weather conditions.

The calorific value, referred to moisture-free and ash-free coal, of samples taken from shipments at destination, tends to be slightly lower than that of the fresh mine samples from the same mine. The deterioration is caused mainly by the freshly exposed surfaces of coal absorbing oxygen from the air. The rate of deterioration varies with the different types of coal and depends on a number of

factors, chief of which are: (1) Size of coal, (2) proportion of surface exposed to circulating air, (3) duration of exposure, (4) temperature and humidity.

It is therefore difficult to assign any definite values for deterioration of coal while in transit. A number of mine and car samples tested by the United States Geological Survey and the Bureau of Mines showed the following average losses in moisture-free and ash-free calorific value of car sample as compared with that of mine sample.

Kind of coal.	Per cent.
Semibituminous, New River and Pocahontas	0.1
Bituminous, Appalachian field	.3
Bituminous, Illinois, Indiana, and Missouri	.8
Subbituminous and lignite	1.3

TABLE III. CALORIFIC VALUE OF COALS FROM VARIOUS STATES

State	Kind of fuel	County	B.t.u. per lb.
Alabama	Soft — Caking	Bibb	13,671
Alabama	Soft — Free-Burning	Jefferson	14.447
Arkansas	Soft — Caking	Sebastian	13,705
Arkansas	Semi-Anthracite — Caking	Johnson	14,125
Arkansas	Lignite	Ouachita	9,519
Georgia	Soft — Free-Burning	Chattooga	12,865
Illinois	Soft — Free-Burning	Williamson	12,920
Illinois	Soft Briquets	St. Clair	13,271
Illinois	Soft — Caking	Saline	13,621
Indiana	Soft — Free-Burning	Greene	13,099
Indiana	Soft — Caking	Pike	13.545
Indiana	Soft Briquets	Parke	11,930
Indian Territory	Soft — Free-Burning	....	13,932
Indian Territory	Semi-Anthracite	....	14,682
Kansas	Soft — Free-Burning	Linn	12,343
Kentucky	Soft — Free-Burning	Union	14,026
Maryland	Soft — Free-Burning	Allegany	14,515
Maryland	Soft Briquets	Allegany	14,717
Missouri	Soft — Caking	Randolph	11,747
Montana	Lignite — Free-Burning	Carbon	11,628
New Mexico	Soft — Caking	Colfax	13,059
New Mexico	Soft — Free-Burning	Colfax	12,721
Ohio	Soft — Free-Burning	Belmont	13,381
Pennsylvania	Soft — Caking	Indiana	14,240
Pennsylvania	Soft — Free-Burning	Cambria	14,119
Pennsylvania	Soft Briquets	Westmoreland	14,382
Tennessee	Soft Briquets	Claiborne	14,092
Tennessee	Soft — Free-Burning	Campbell	14,008
Tennessee	Soft — Caking	Grundy	13,257
Texas	Lignite — Free-Burning	Wood	11,131
Utah	Soft — Free-Burning	Summit	12,586
Virginia	Anthracite — Free-Burning	Montgomery	12,679
Virginia	Soft — Caking	Tazewell	14,177
Washington	Sub-bit.— Free-Burning	King	11,772
Washington	Soft — Free-Burning	Kittitas	12,996
West Virginia	Soft — Free-Burning	Marion	13,964
West Virginia	Soft — Caking	Kanawha	13,995
Wyoming	Soft — Free-Burning	Carbon	12,222
Wyoming	Sub-bit.— Free-Burning	Uinta	12,488

The valuations in Table III were obtained at St. Louis testing plant from 139 samples of coal. The heating values of the various coals were established by "actually burning one grain of the air-dried coal in oxygen in a Mahler bomb calorimeter."

Calorific Value of Selected Free-Burning and Caking Soft Fuels. The data in Table III are from U. S. Geological Survey Bulletin No. 332 and U. S. Bureau of Mines Bulletin No. 23. See Fig. 3.

TABLE IV. COMPOSITION AND HEAT VALUES OF ANTHRACITE COALS

Locality	Fixed carbon	Volatile	Moisture	Ash	Sulphur	B.t.u. per lb.
Anthracite						
Penna.,	78.60	...	...	14.80	0.40	.....
" Buckwheat	81.32	3.84	3.88	10.96	0.67	12,200
" Wilkesbarre	76.94	6.42	1.34	15.30	...	11,801
" Scranton	79.23	3.73	3.33	13.70	...	12,149
" "	84.46	5.37	0.97	9.20	...	12,294
" Cross Creek	89.19	1.96	3.62	5.23	...	13,723
" Lehigh Valley	75.20	7.36	1.44	16.00	...	12,423
" Lykens Valley	76.94	6.21	...	....	...	15,300
" " "	81.00	5.00	...	....	...	15,300
" Wharton	86.40	3.08	3.71	6.22	0.58	15,000
" Buck Mt.	82.66	3.95	3.04	9.88	0.46	15,070
" Beaver Meadow	88.94	2.38	1.50	7.11	0.01	.....
" Lackawanna	87.74	3.91	2.12	6.35	0.12	.....
Rhode Island	85.00	....	...	7.00	0.90	.....
Arkansas	74.49	14.73	1.52	9.26	...	13,217
Semi-Anthracite						
Penna., Loyalsock	83.34	8.10	1.30	6.23	1.03	15,400
" Bernice	82.52	3.56	0.96	3.27	0.24	15,050
" "	89.39	8.56	0.97	9.34	1.04	15,475
" Wilkesbarre	88.90	7.68	...	3.49	...	14,199
" Lycoming Creek	71.53	13.84	0.67	13.96	0.03	.....
Virginia, natural coke	75.08	12.44	1.12	11.38	0.47	.....
Arkansas	74.06	14.93	1.35	9.66	...	.....
Indian Territory	73.21	13.65	5.11	8.03	1.18	13,662
Maryland, Easby	83.60	16.40	...	....	...	11,207

TABLE V. HEAT VALUE AND COMPOSITION OF VARIOUS FUELS

Name of combustible	Composition C	H	Volatile matter	Ash	Calorific power B.t.u.
Carbon	1.00	...	...	...	14,400
Anthracite coal	0.90	0.03	0.03	0.01	13,500
Bituminous Coal	0.85	0.05	0.06	0.06	14,400
Lignite	0.70	0.05	0.20	0.05	11,700
Peat	0.55	0.05	0.30	0.10	9,000
Peat 0.30 water	0.39	0.04	0.50	0.07	7,200
Coke	0.85	0.05	...	0.10	12,600
Peat — charcoal	0.82	...	...	0.18	9,000
Dry wood	0.48	0.06	0.05	0.01	7,200
Wood 0.20 water	0.40	0.05	0.25	0.01	5,400
Wood charcoal	0.80	...	0.04	0.07	10,800
Hydrogen	...	1.00	...	...	62,000
Carbonic oxide	0.43	...	0.57	...	4,320
Illuminating gas	0.62	0.21	0.17	...	18,000
Gas from blast-furnace	0.06	0.02	0.92	...	1,620

NOTE. Above information is quoted from standard authorities. Not guaranteed.

Influence of Ash on Value of Coal. All motive power officers, locomotive engineers and firemen are familiar with the trouble occasioned by what is designated as "bad coal," which makes clinkers as well as fills the firebox with ashes, so that the capacity of the locomotive is very materially reduced, resulting in delays and various other troubles, due not to inferiority in the coal itself,

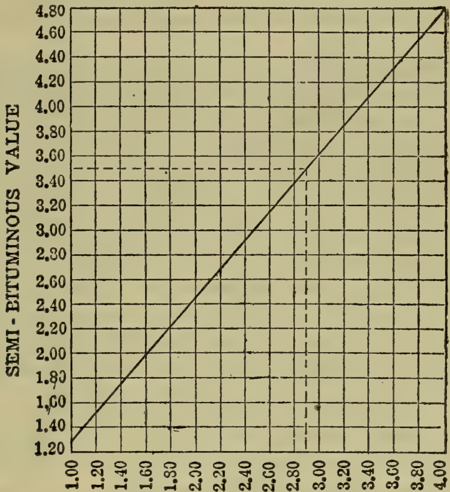


Fig. 3. Relative Value of Semi-Bituminous and Anthracite

but to the fact that the ash in or associated with the fuel is excessive. In Railroad Age Gazette, July 30, 1909, there are given two diagrams, Figs. 4 and 5, the first illustrating value of coal fuel with varying percentages of ash, and the second, showing the results of experiments from which Fig. 5 is derived.

These experiments were made with a Babcock & Wilcox boiler served with a chain grate stoker. A special lot of four cars of what is known as No. 4 washed coal from Williamson county, Illinois, were provided to insure that no effect produced would be due to irregularity in size. In preparation it was passed over a screen having round perforations ¼ in. in diam. and through a screen having round perforations ¾ in. in diam. The coal as received contained approximately 8% ash. The first experiment was run with this coal in condition as received. In the test of the following day a small quantity of ash-pit refuse was mixed with it, and on each succeeding day a gradually increasing quantity of ash-pit refuse was added to the coal and thoroughly mixed. This process was continued until the efficiency and capacity dropped

to zero, or in other words, until there was no water evaporated from the coal burned, notwithstanding the fact that 60% of the fuel composition was pure coal.

The above mentioned experiments were conducted for the Commonwealth Edison Co., Chicago, and they refer to conditions of stationary boiler service rather than of locomotive. Some results plotted from tests made by the United States Geological Survey using coal containing ash ranging from 5 to 15% on hand-

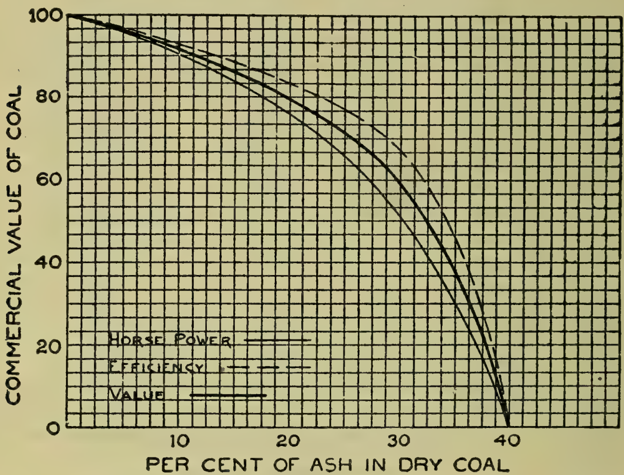


Fig. 4.

fired grates, conform very closely to the corresponding portion of the curve shown in Fig. 5.

The matter of ash in locomotive fuel may be considered from two standpoints; one, the desirability of employing fuel which is low in ash, the other, the removal of the ash as rapidly as it accumulates, each tending to the same result. It has been the author's experience that by frequently shaking the grate, the ash accumulation could be so disposed of that an engine would come in at the end of a division with the fire in apparently as good condition as when leaving. This, however, added very materially to the labor required on an engine, but more recently, grate-shaking apparatus, which is operated by steam, has been proposed and also employed to a limited extent.

The whole matter of the ash in locomotive fuel is one of the very first importance, probably much greater than has been realized. The characteristic of smallness in size, which cuts a considerable figure in stationary practice, is largely absent in the case of locomotives, for the reason that the fine coal is carried out of

the stack by the intense draft and does not clog the fuel to such harmful extent, leaving the ash as the greatest cause of trouble with the railway fuel, which results in many so-called engine failures.

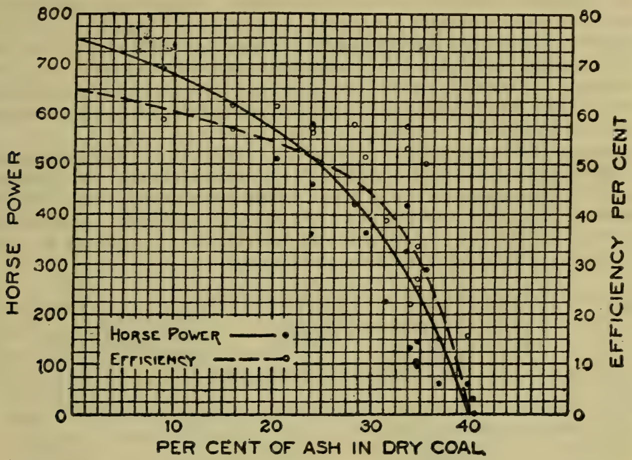


Fig. 5.

Cost of Preparing Powdered Coal. W. L. Robinson states that a general average from available data, covering a period of the past 5 or 10 years of cement and metallurgical plants, will justify the following conservative estimates for plants of different sizes, assuming the cost of the raw coal at from $1 to $2 per short ton. The material will require crushing and have a moisture content of from 5 to 10% when placed in the dryer.

Capacity of plant in short tons per hr.	Average total cost for preparation per short ton, cts.
2	25 to 50
3	20 to 45
4	16 to 40
5	14 to 35
10	12 to 30
25	10 to 20

The fuel required for drying the coal will average from 1 to 2% of the coal dried, and the distribution of the total cost is approximately as follows:

	Per cent.
Fuel for drying	10
Power for operation	30
Labor	30
Maintenance and supplies	25
Interest, taxes, insurance and depreciation	5
Total	100

Coal Burned per Sq. Ft. of Grate Area. Fig. 6 gives the results of tests on briquettes and run-of-mine coal noted by W. F. M. Goss in Bul. No. 363, U. S. Geological Survey.

The experiments were made on the U. S. torpedo boat *Biddle* by Kenneth McAlpin of the U. S. Navy Department and W. T. Ray and H. Kreisinger of the U. S. Geological Survey. The run-of-mine coal from the New River district of West Virginia was low-volatile, bituminous or semi-bituminous in character and very friable. It was tested after an exposure of 23 days. The briquettes were made on Johnson and Renfrow machines using 6% of water-gas pitch binder.

Cost of Briquetting Coal. From a paper on "Coal-Briquetting in the United States," by E. W. Parker, appearing in the Transactions of the American Institute of Mining Engineers, and published by them with the permission of the director of the U. S. Geological Survey we abstract the author's description of a plant in New York City and the costs of its operation.

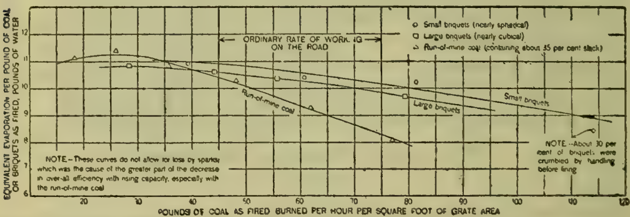


Fig. 6. Evaporative efficiency of briquettes and coal.

The Mashek press in this plant has a capacity of about 14 tons per hr. of 2-oz. briquettes, but because of unfavorable conditions its capacity is about 10 tons per hr. The briquettes most in demand were found to be the 2-oz. size, which corresponds with the stove-coal size of anthracite. The weight varies with the nature of the dust from which the briquette is made, and it has been found that in using coke-breeze a 2.5-oz. briquette is most desirable, and about a 3-oz. if made of soft coal and lignite. The press is designed so that a charge of the mould shells can be made in about 2 hrs.

The arrangement of the plant is such that the anthracite-dust is elevated to a dust bin, from which it is drawn by a feed-conveyor so arranged that the feed is constant and can be regulated as desired. This conveyor discharges into a chain elevator, which in turn discharges into a battery of five 18-in. rotary driers and heaters. These are superimposed one above the other and all bricked in. The material is conveyed through these driers by means of screw-mixers until it passes into the following elevator.

On the side of these driers is constructed a furnace, the products of combustion from which are distributed into the driers through

openings into different units, so that no unit gets heat sufficient either to char the dust or to burn out the iron-work of the paddle-conveyor. An exhaust-fan draws off the products of combustion and the moisture. The temperature of the discharge-gases and moisture from the drier rarely exceeds 212 degs. F. After the material passes out of the drier into the elevator it is elevated and dropped into a 36-in. Williams pulverizer, where the larger pieces are crushed, so that everything passes through about a 12-mesh screen. From the pulverizer the material is again elevated to another series of mixers and coolers similar in construction to the driers. The anthracite dust at this point has a temperature of about 300 degs. F. The coal-tar pitch is here introduced by means of a pitch-pump so arranged as to deliver a definite quantity of pitch, as desired. Alongside of this last battery of mixers is a small furnace which heats the two upper mixers, maintaining an even temperature of the mixture and not allowing it to stiffen or set. From the last mixer the material drops to an elevator which takes it up to the second floor and discharges it on to an 18-in. belt conveyor, which delivers the material over the press and into the hopper. The press is continually discharging the briquettes into a perforated-pan conveyor, which conveys them to the briquette bin. While on this conveyor the briquettes are subjected to a heavy spray of water in order to cool and clean them.

The coal-tar pitch used in this plant is of the ordinary roofing-hardness; it is delivered by lighter on an adjacent dock and carted to the pitch melting house.

The plant requires about 125 h.p. to turn out 10 tons per hr.

The cost of manufacture is as follows:

Pitch:

Using 6% of pitch at $10 per ton	$0.60
Deducting increased weight of product due to 6% of pitch and calculating product at $5 per ton	0.30
Net cost of pitch	$0.30

Fuel:

For boilers, broken coal and screenings, broken briquettes, 4 tons per day of 10 hrs., at $2.50 per ton	$10.00
Per ton of briquettes	0.10
For heaters, driers and pitch-melting, 3 tons at $2.50 per ton of briquettes	0.075

Labor:

	Per day
1 foreman	$ 5.00
2 pitch-melters	3.50
1 dust-bin man	1.75
1 engineer	3.50
1 man on second floor	1.75
1 man on ground floor	1.75
1 night watchman	1.75
1 oiler	1.75
	$20.75
Per ton of briquettes	$0.21

Miscellaneous:

Wear and tear, per ton of briquettes	$0.10
Lubricating oil, per ton of briquettes	0.01
Insurance	0.005
Interest on capital invested $40,000 at 6%	0.10
Office expense, telephone, stenographer and stationery, $2,000 per annum	0.09
	$0.99
Anthracite (dust at $1.40 per long ton) per net ton of briquettes	1 25
Total cost of briquetting	$2.24
Re-briquetting 3% of breakage and abrasion, charging it back to plant as dust, per ton of briquettes	0.06
Net cost per ton of briquettes	$2.30
Wholesale selling-price in bin	4.80
Net profit per short ton	$2.50

Cost of Briquetting Coal. M. H. Blauvelt in the Transactions of the American Institute of Mining Engineers, March, 1910, described the fuel briquetting plant of the Solvay Co., at Detroit, Mich., and gave the following figures for the plant, the capacity of which has been brought up to 9 tons per hr. and may reach 10 tons:

Power consumed in motor driving in different parts of the plant was as follows:

	Brake h.p.
Breeze conveyor to drier	1.50
Breeze drier and ventilating fan	2.85
Pulverizing mill	22 00
Elevator shafting and rotary mixer	10.00
Briquetting press	25.00
Total	61.35

Tests extending over a number of days showed a consumption of 206 lbs. of steam per ton of 'riquettes produced, and the writer says that the above steam consumption per ton of product would undoubtedly be decreased by a larger output.

Labor cost of briquetting was as follows:

	Cost per hr.
1 foreman	$0.50
1 pressman	0.26
1 oiler, breeze-drier and conveyor man	0.18
1 pitch man	0.18
1 briquette loader	0.19
2 laborers, at 17 cts.	0.34
Total	$1.65

This labor cost amounts to 18.3 cts. per ton, when producing 9 tons of briquettes per hr. Two presses would double the output, but would only require two more men at 18 cts., and a second pressman at 26 cts. per hr., which would reduce the labor cost to 12.6 cts. per ton.

Cost of briquetting per ton of product with and without coke-

breeze, and a plant similar to that described, producing 9 tons of briquettes per hr., was as follows:

	Using 50% of breeze	Using 100% of coal
Labor	$0.183	$0.183
Power, at 1.25 cts. per kw.-hr.	0.072	0.072
Steam, 206 lbs., at 0.5-ct. per hp.-hr.	0.034	0.034
Breeze-drier and superheater fuel	0.03	0.011
Miscellaneous supplies, oil, waste, lights and water	0.03	0.03
Repairs on rolls	0.191	0.035
Other repairs	0.06	0.035
Total	$0.60	$0.40

The cost of the pitch for binder and of the coal, coke-breeze, or other fuel used, must be added to these figures to obtain the total operating cost of such a plant. And the following estimate is given, assuming the suitable slack coal can be obtained at $2, coke-breeze at $1, and pitch at $8 per ton, delivered at the plant, and assuming the use of 7.5% of binder with the coal and 9% with the mixture of coal and breeze.

Estimated cost of one ton of briquettes on above bases was as follows:

	Equal parts of coal and breeze	All coal
0.455 ton coal, at $2	$0.91	...
0.925 ton coal, at $2	...	$1.85
0.455 ton breeze, at $1	0.455	...
9% of pitch, at $8	0.72	...
7.5% of pitch, at $8	...	0.60
Cost of briquetting, as above	0.60	0.40
Total	$2.685	$2.85

These results were obtained with the simplest form of apparatus for preheating the air. All the steam required for operating the plant, handling and storing coal, distilling ammonia, etc., being produced in the waste heat assisted by the breeze that the plant produced.

Cost of Coal Briquetting in the West. The following costs are given in the Proceedings of the American Institute of Mining Engineers, 1905:

ESTIMATED COST PER TON OF BRIQUETTES IN WESTERN AMERICA

Labor	$0.16
Oil and grease	.006
Sundry stores	.01
Steam-fuel	.04
Depreciation	3.05
	$0.266
8% of pitch at $12 ton	.96
1,840 lbs. of coal-slack at $1	.94
	$2.166

Cost of plant was $10,500 to $14,000.

Sales price of briquettes is 66–80% price of best lump-coal.

In Germany the sale price is $2 to $3 per metric ton.

In East America coal-slack is almost worthless and cost of briquettes will be less than $2.17 per ton.

By-Products Coke Ovens (after W. H. Blauvelt) give results per ton of coal coked:

Type of oven	Fuel gas per cent.	Surplus gas per cent.	Steam produced, lbs.
No air preheating	70	30	1,050
Partial air preheating	60	40	800
Maximum air preheating	40	60	0

Distribution and Consumption of Power in a By-Product Coke Oven Plant having Capacity of 1,300 Tons of Coal per Day. (After W. H. Blauvelt.)

Daily power consumption in kw.-hrs. for various operations was as follows:

Lighting	599
Pumps handling ammonia liquor	390
Scrubbers and pumps in by-product recovery-plant	1,283
Coal-charging and coke-pushing	192
Coal-conveyors	393
Coal-unloading	282
Coal-storage	102
Crushing and pulverizing	287
Coke-handling	686
Pumping water	1,800
Total power consumption and distribution	= 6,014
For 1,300 tons of coal coked	= 4.63 kw. per ton

F. E. Lucas in a paper before the American Institute of Mining Engineers in 1912 stated that a modern by-product oven, run at a reasonable capacity will give 50% or more of surplus gas from a coal of about 28% volatile-content. The surplus gas is the gas over and above the quantity needed to keep the oven up to the required temperature. This surplus gas should run from 450 to 500 B. t. u. per cu. ft. The quantity of surplus gas is approximately 5,000 cu. ft.; hence, $5{,}000 \times 450 = 2{,}250{,}000$ B. t. u. per ton of coal carbonized is available for the production of power, = 93,750 B. t. u. per hr. The builders of gas-engines tell us we can get 1 h.p. on a heat-consumption of 11,000 B. t. u. On that basis, we find 8.5 h.p. per hr. from the surplus gas from 1 ton of coal.

The Cost of Manufacturing Coke. In the older so-called beehive type of oven nothing is recovered except the coke, in the so-called by-product type of oven, in addition to the coke itself various kinds of by-products are recovered, consisting mainly of tar, ammonia, and gas, varying greatly in quantity and quality with the composition of the coal. In America, coals similar to those of the Pocahontas region, containing as low as 16%, or less of volatile matter, stand at one end of the classification, while in Europe, some coals are coked which contain not more than 13% of volatile matter. These produce the maximum yield of coke and the minimum yield of by-products. At the other end of the list are the gas-coals, containing as much as 38 or 40% of volatile matter, and yielding correspondingly small amounts of coke.

The economic advantages of the bee-hive oven are that it is quickly built, has relatively low first cost, and can be operated by low grade labor. It can be put out of run at relatively small cost, and can easily be started up again after a shut-down.

Since the organization of the United States Steel Corporation the conditions in the steel business in America have been much more stable and uniform and the relative advantages of the beehive type of oven have decreased in proportion as the stability of the steel industry has increased. In addition to this the coals which are best adapted to the beehive are becoming less plentiful.

The beehive process consists essentially in heating the coal with controlled admission of air to the coke in the chamber, to the end that the heat necessary for the distillation of the volatile matter is produced by combustion within the oven chamber; whereas in the by-product oven the process is a true dry distillation, in which no air is admitted to the chamber and the heat necessary for the distillation is supplied through the chamber walls.

The by-product oven is generally located at the point of consumption of the coke or at some center of distribution. The disadvantage of freight charges thus entailed, on from 1.2 to 1.4 tons of coal for every ton of coke produced, is partially offset by the fact that the coal usually carries a lower freight-rate than coke, is more easily transported, and is not so likely to be injured by handling. Thus a blast-furnace plant, having its own coke ovens at the furnace may possess an assured supply of coke independent of weather or shipping conditions, and it is quite common for such a plant to accumulate a stock of from one to eight months' supply of coal, the cost of the coal stock pile with the cost of the facilities for handling coal being a charge upon the coke plant. Another advantage of this arrangement is that the by-products so produced are much nearer to their market and the gas is often available for industrial uses or for municipal lighting. Such locations are likely to be well adapted to the securing of diversified labor and the various processes of the by-products of this type of oven. Still another important advantage in locating the oven-plant at the point of consumption is, that it permits a convenient assembling of several kinds of coal at the ovens, this mixture permitting the best quality of coke to be produced, while the coke made from any one of the coals alone might be of inferior quality or possibly not well adapted to the particular requirements of the market at the time of manufacture.

W. H. Blauvelt of Syracuse, N. Y., to whose paper at the Cleveland meetings of the A. I. M. E., October, 1912, we are indebted for the above facts, says that a complete beehive oven plant complete in every respect and constructed in the best manner to include all the equipment besides the ovens and their immediate appurtenances such as electric power-plant, water-supply, railroad-approaches and sidings, coal-handling equipment, etc., would cost about $950 per oven; 675 to 700 tons per annum representing the average output per oven of such a plant, this giving a plant-cost of $1.38 per ton of coke produced per year, whereas a by-product oven-

plant of 80 ovens, complete in every respect, and built in the best manner, and costing $1,100,000 would produce 425,000 tons of coke per annum from average coal, this amounting to $2.58 per ton of coke per year. Thus, on the basis of the same output of coke alone the by-product plant costs 1.86 times the beehive type. Economically speaking, this is hardly a fair basis for a comparison, because the dollar output of the by-product plant would be considerably higher than unity as compared with that of the other. Moreover, the higher price plant is usually built for more than twice as long a life as that of the beehive plant.

In 1912 the by-product coke ovens in America had often a capacity for as much as 20 tons of coal per oven per day, and in the rate of coking, American practice was well ahead of Europe. Several types of ovens coking regularly at the rate of from 50 to 55 min. per in. of oven width, this high rate being made possible partly by better control of the heating-systems, and partly by the adoption of silica brick, which for many years has been used generally in bee-hive oven construction.

Economic Comparison between Beehive and By-Product Ovens. Mr. Lucas in Proc. Am. Inst. Mining Engrs., 1905, gives the following:

Bee-Hive.

Ordinary type, 12.5 ft. in diam.
Cost from $700 to $1,200 per oven.
Produces 4 net tons of coke in 48 hrs. = 2 net tons in 24 hrs.
Yield of coke from coal, 60%.
By-products and surplus gas = none.

By-Product Ovens.

Oven charge, 9 tons.
Coking-time, 24 hrs.
(Ovens may be larger or smaller than this, but 9 tons would probably be about the average charge for the modern type of oven.)
Coke produced on 70% yield = 6.3 tons of coke per oven in 24 hrs.

By-Products.

Ammonium sulphate, 22 lbs. per net ton of coal = 31 lbs. per net ton of coke. Value, 2.25 cts. per lb. above cost of manufacture = 70 cts. per ton of coke made.
Tar. 8.5 gals. per ton of coal = 10.7 gals. per ton of coke, at 2 cts. per gal. = 21 cts. per ton of coke.
Surplus gas, 5,000 cu. ft. per ton of coal = 7,143 cu. ft. per ton of coke, at 10 cts. per 1,000 cu. ft. = 71 cts. per ton of coke.
Total value of by-products as above was as follows:

Ammonium sulphate	$0.70
Tar	0.21
Gas	0.71
Value per ton of coke	$1.62

Add to the above the difference between 60% yield in bee-hive ovens and 70% in by-product ovens on the same coal. Taking coal at $1.50 per ton:

Coal per ton of coke produced in bee-hive oven......	$2.50
Coal per ton of coke produced in by-product oven.....	2.14
Balance in favor of by-product oven	$0.36

So that the total saving in coal and by-products equals $1.62 plus $0.36 = $1.98 per ton of coke made, = $12.45 per oven in 24 hrs. = $4,551.55 per oven per year. Or for by-products alone, without saving in coal, $3,723 per oven per year.

For a plant of 100 ovens, saving = $455,155 per year.

Cost of 100-oven plant complete, approximately $1,000,000.

A 100-oven plant of above capacity will produce 630 tons of coke per day = 229,950 tons per year, working on 24 hrs. coking time.

If benzol is recovered it will further add to the income from by-products.

Output of Gas from a By-Product Plant. Mr. Blauvelt states that from two plants within his knowledge, using coal containing less than 27% volatile matter, the year's average of gas per ton of coal coked was over 4,200 cu. ft., heat units from the two plants averaging over 2,600,000 B. t. u. per net ton of coal coked.

Cost of Gas from a By-Product Coke Oven Plant. For the gas actually distributed and sold, it is found by the Citizens Gas Co. of Indianapolis, Ind., that the cost of distribution and management (not including taxes and insurance) was 13.1 cts. per 1,000 cu. ft. The accompanying figures show the expenditures and receipts per ton of coal carbonized (1) as actually occurring for the first six months of operation, using 260 tons per day, and (2) as estimated for regular working at 375 tons per day:

	Actual results	Estimated
Coal per day	260 tons	375 tons
Expenditures per ton:		
Cost of coal	$2.494	$2.750
Labor, supplies and repairs	.334	.686
Distrib. and management	.349	.736
Taxes and insurance	.099	.149
Total	$3.276	$4.321
Receipts per ton:		
Coke	$2.336	$2.450
Ammonia	.447	.405
Tar	.242	.180
Gas	1.542	2.280
Total	$4.568	$5.315

There are 50 by-product ovens, and operation was begun in November, 1909; part of the time only 25 ovens were in use, and when all were in use (for four months) they were operated on the

slowest possible schedule. The plant is designed for charging 60 ovens per day, but during the four months only 36 were charged daily. Even on this slow schedule the gas production was 50,000,000 cu. ft. in excess of the demand. (Engineering News, Sept. 22, 1910.)

Cost of Burning Charcoal. The charcoal plant at Gorgona, Panama, has discontinued operations, with a stock on hand sufficient for a year's supply. Since April, 1911, 30 kilns have been burned, producing 350,229 lbs. The cost of this, including the erection of the kilns, was $1,592.76. The average cost of producing charcoal was 45½ cts. per 100 lbs.; the two last kilns cost 29 cts. per 100 lbs. The price of charcoal a year ago was $1.10 per hundredweight, at which the amount produced in the year past would have cost $3,852.52, so that the saving effected by the operations of the plant amounted to $2,259.76. The principal use of charcoal in the canal and railroad work is in starting fires in locomotives and steam shovels.

Comparative Costs of Fuel. We are indebted to the Automatic Gas Producer Company, New York, and to Power, where they were published in 1906, for the accompanying figures showing the comparative costs of fuel per h.p.-year for steam and gas engines under various conditions of operation and cost per unit of fuel. The figures are based on 10 working hours per day and 300 working days per year, and the range of prices and consumption rates are such as to enable one to make very satisfactory comparisons.

STEAM ENGINE AND BOILER

Coal per h.p-hr.	Cost per hp.-year					
Coal at	3 lbs.	4 lbs.	5 lbs.	6 lbs.	7 lbs.	8 lbs.
$2.00 a ton	$9	$12	$15	$18	$21	$24
2.50 "	11	15	19	22	26	30
3.00 "	13	18	22	27	31	36
3.50 "	16	21	25	31	37	42
4.00 "	18	24	30	36	42	48
4.50 "	20	27	34	40	47	54
5.00 "	22	30	37	45	52	60

GAS ENGINE

Using 20 cu. ft. of illuminating gas per horsepower hour:

Cost per 1,000 cu. ft......	$0.75	$0.80	$0.85	$0.90	$0.95	$1.00
Cost per h.p.-year	45.	48.	51.	54.	57.	60.

Using 15 cu. ft. of natural gas per h.p.-hr.:

Cost per 1,000 cu. ft.	$0.16	$0.18	$0.20	$0.22	$0.24	$0.25
Cost per h.p.-year	7.20	8.10	9.00	9.90	10.80	11.25

Using producer gas: 1¼ lbs. of coal per h.p.-hour:

Cost of coal per ton	$2.00	$2.50	$3.00	$3.50	$4.00	$4.50	$5.00
Cost per h.p.-year..	3.34	4.17	5.00	5.83	6.67	7.50	8.33

GASOLENE ENGINE

Using one pint of gasolene per h.p.-hr.:

Cost per gal.......	$0.08	$0.09	$0.10	$0.11	$0.12	$0.13	$0.15
Cost per h.p.-year..	30.00	33.75	37.50	41.25	45.00	48.75	56.25

Comparative Cost of Power with Coal versus Oil Fuel. Reginald Trautschold published Tables VI and VII, giving the method of

calculating the fixed charges on two 500 h.p. plants, one burning coal and the other oil, in Power, Mar. 4, 1913.

TABLE VI. AVERAGE FUEL COST PER H.P.-YR. WITH VARIOUS PRICES OF COAL AND OIL

FUEL COSTS

Fuel oil per gal.	Fuel oil per h.p. yr.	Coal per ton	Coal per h.p. yr.
$0.01	$9.00	$1.00	$7.20
0.015	13.50	1.50	10.80
0.02	18.00	2.00	14.40
0.025	22.50	2.50	18.00
0.03	27.00	3.00	21.60
0.035	31.50	3.50	25.20
0.04	36.00	4.00	28.80
0.045	40.50	4.50	32.40
0.05	45.00	5.00	36.00
0.055	49.50	5.50	39.60
0.06	54.00	6.00	43.20

AVERAGE FIXED CHARGES OF POWER HOUSE

Oil Burning Plant

Engine room:	
Building, etc.	$10
Engine, accessories, piping, etc.	30
Foundations, installation, etc.	5
Total per h.p.	$45
Depreciation, total cost	5%
Repairs	2%
Interest	6%
Insurance	1%
Taxes, ⅔ cost	2%
Total per h.p.	$22.00
Boiler room:	
Building, foundations, etc.	$4.50
Chimneys, flues, etc.	7.00
Boilers, etc.	7.50
Oil burning systems (complete)	3.00
Total per h.p.-yr.	$22.00
Depreciation, total cost	5%
Repairs	2%
Interest	6%
Insurance	2%
Taxes, ¾ cost	2%
Total per h.p.-yr.	$3.63
Cost of operation:	
Engine room —	
Attendance	$1.80
Supplies	0.80
Total per h.p.-yr.	$2.60
Boiler room —	
Attendance	$1.10
Supplies	0.47
Total per h.p.-yr.	$1.57
Total fixed charges, per h.p. year	$15.00

Coal Burning Plant

Engine room	$ 7.20
Boiler room:	
Building, foundations, etc.	$ 5
Chimneys, flues, etc.	8
Boilers, feed pumps, etc.	12
Total per h.p.	$25
Depreciation, total cost	5%
Repairs	2%
Interest	6%
Insurance	1%
Taxes, ¾ cost	2%
Total per h.p.-yr.	$3.87
Cost of operation:	
Engine room	$2.60
Boiler room —	
Attendance	$1.90
Supplies	0.90
Total per h.p.-yr.	$2.80
Total fixed charges, per h.p. per yr.	$16.47

TABLE VII. AVERAGE FUEL COSTS PER H.P.-YR. WITH VARIOUS PRICES OF COAL AND OIL

Oil Burning Plant.

Cost of oil per gal.	Steam power per h.p. year
$0.01	$24.00
0.015	28.50
0.02	33.00
0.025	37.50
0.03	42.00
9.035	46.50
0.04	51.00
0.015	55.50
0.05	60.00
0.055	64.50
0.06	69.00

Coal-Burning Plant.

Cost of coal per ton	Steam power per h.p. year
$1.00	$23.67
1.50	27.27
2.00	30.87
2.50	34.47
3.00	38.07
3.50	41.67
4.00	45.27
4.50	48.87
5.00	52.47
5.50	56.07
6.00	59.67

These figures are based on those obtained for various plants for about 500 h.p. and the results are applicable to both smaller and larger plants of reasonable limits, if only a relative comparison between oil and coal be desired, this relation holding true principally

because the efficiency of the plant is increased with an increase in size, while the fixed charges per h.p. are correspondingly reduced, all in the same proportion.

Comparative Cost of Coal and Oil Fuel for Railroads. The following figures relating to the relative cost and efficiency of coal and of oil are current in California:

Two and one-half barrels of oil are the equal of one ton of coal in thermal units. In other words, the same amount of heat can be obtained from 2½ bbls. of oil as can be obtained from one ton of coal. But the difference in price is very great. Coal, producing the same amount of heat per ton as 2½ bbls. of oil, costs in California anywhere from $6 to $8 per ton wholesale. Two and one-half bbls. of oil, figured at the market delivery price of $1 per bbl., costs $2.50 — a saving of from $3.50 to $5.50 on every ton of coal displaced by oil.

Comparative Sizes of Smoke Stacks Necessary with Fuel Oil as Compared with Coal. K. G. Dunn of San Francisco in the Journal of the American Society of Mechanical Engineers for 1911, has called attention to the fact that the amount of draft necessary to overcome the friction of the fuel bed in a coal furnace may vary between 35 to 70% of the total draft head, whereas when fuel oil is used there is no draft friction through the fuel and a smaller and shorter stack will give the necessary draft for proper circulation of the hot gases through the furnace. Ordinarily for oil burning, a stack of 50% draft capacity is not required, but for a coal furnace may safely be designed.

Comparative Quantities of Oil and Coal Consumed for the Same Quantity of Power Produced. Howard Stillman gives the figures in Table VIII of comparative tests on the Southern Pacific Railroad, the comparison being with ordinary bituminous coal of about 13,350 B. t. u. and also Table IX for steamships.

TABLE VIII. LOCOMOTIVE TESTS ON OIL AND COAL

Type of locomotive	Number in service	Evaporation, 2000 lbs. coal equivalent to fuel oil, gals.
Eight-wheel 18-24	50	144
Ten-wheel	294	151
Mogul	176	146
Twelve-wheel	67	158
Consolidation	139	162
Atlantic	19	144
Mallet consolidated	17	No coal record

Mean of results — 152 gals. = 3.6 bbls. = 2,000 lbs. coal.

This is the record of coal burned during the last 6 months of 1901 and oil burned during the last 6 months of 1908 on the steamers of the Southern Pacific Company. These figures are not from evaporated tests, but cover the service of 11 steam boats and are from the official accounting records.

Comparative Coal and Oil Consumption of the "Nevadan" of the Hawaiian American Steamship Company was as follows:

	Total i. h.p.	Fuel	Total consumption of fuel	Coal per i. h.p.	Oil per i. h.p.
Voyage No. 1....	1,833	coal	2,269 tons	2 lbs.	......
Voyage No. 2....	2,196	oil	9,126 bbls.	....	1.1 lbs.

Voyage No. 1 with coal was from San Diego to New York and No. 2 with oil was from New York to San Diego. The figures are from the report of the Naval Liquid Fuel Board published in 1904 and quoted in the Journal of the American Society of Mechanical Engineers for Aug., 1911. Part of the coal burnt was Eurela and part Coronel. The heat value of the coal was not given. The ship was new and fitted with triple-expansion engines using the Howden system of forced draft, and the Lassoe-Lovekin oil-burning system. When oil was consumed, six men were necessary in the fireroom as against fifteen for coal. The saving in space for cargo on account of the decreased bulk of the oil fuel was 457 tons, which was supposed to have resulted in a financial gain to the company from all causes, including the saving in the cost of the oil fuel, of $500 per day.

TABLE IX. STEAMSHIP TESTS OF OIL AND COAL

Steamer	Tons coal consumed last six months of coal burning	Mileage for corresponding period	Miles per ton of coal consumed	Barrels oil consumed, 6 months (42 gals. per bbl.)	Mileage for corresponding period	Miles per bbl of oil consumed	Equivalent of one ton of coal for equal mileage in bbl. of oil
Berkeley	2,764	18,592	6.72	11,207	21,130	1.89	3.56
Piedmont	4,223	19,548	4.63	15,414	20,808	1.35	3.43
Oakland	3,209	18,348	5.72	13,603	19,894	1.46	3.92
Bay City	2,889	21,536	7.45	11,548	20,943	1.81	4.12
Encinal	3,703	20,284	5.47	10,512	19,678	1.87	2.93
Newark	1,860	9,372	5.04	6,559	10,631	1.62	3.11
Transit	2,581	16,715	6.48	9,548	17,922	1.88	3.45
El Capitan	1,019	7,238	7.10	3,431	6,072	1.77	4.01
Solano	4,516	5,480	1.21	17,151	7,143	0.42	2.88
Apache	1,971	18,992	9.64	7,996	21,380	2.67	3.61
Modoc	2,265	20,685	9.13	7,682	21,170	2.76	3.31
Totals and Resultant means	31,000	176,790	5.70	114,651	186,771	1.63	...

Mean equivalent of 1 ton of coal in bbl. of oil, 3.495.

Comparative Cost of Fuel as Between Coal and Oil on a Small Coasting Steamer. (J. H. Hopps in the Journal of the American Society of Mechanical Engineers, Aug., 1911.) For an average period of 6 months in each case the cost of fuel per hr. of actual steaming was as follows: Coal at $5.25, $2.65 per hr.; oil at $0.70 per bbl., $1.64 per hr.

Tests on Two Tugs on San Francisco Bay, Owned by the Santa Fe Railroad Company. Tests were made in 1903 and quoted by

Mr. Hopps, whose detailed data were destroyed in the San Francisco fire, the summary of the results only remaining. The tests were made with great care, the feed of water and fuel oil being weighed on platform scales, which was feasible on account of the water of San Francisco Bay being smooth. The machinery of the 2 vessels were identical with the exception of the boilers. One ship, the *Richmond*, was fitted with a boiler of the Scotch marine type, 13 ft. mean diameter by 11 ft. long, with three Morrison furnaces, 3 ft. 6 ins. in diameter by 7 ft. 10 ins. long, and 230 tubes 3½ ins. in diameter by 7 ft. 10 ins. long. The depth of the combustion chamber is 36 ins. and the total heating surface is 2,136 sq. ft. The *A. H. Payson* is fitted with a Babcock and Wilcox marine water-tube boiler, total heating surface 2,770 sq. ft. The engines in both cases are compound engines, high-pressure cylinders 20 ins. in diameter, low-pressure cylinders 42 ins. in diameter, and stroke 24 ins.

A large number of tests were made on these vessels in actual service when towing car floats to and from Point Richmond. In addition, a 5-hr. test, running steadily without a tow, was made on each boat, with the results given in Table X.

TABLE X. RESULTS OF FUEL TESTS OF TUGS

FIVE-HOUR RUN, TUG A. H. PAYSON (Aug. 2, 1903)

Time	R.p.m.	H.p.	Water used	Oil used	Water evap. actual	Water evap. from and at 212 degs.	Factor of evap.	Water per i. h.p.	Oil per i. h.p.	Speed knots
11.00	...	...	.....	...	...	....	....	...	...	....
12.00	95.3	535	11,475	853	13.4	14.68	1.095	21.4	1.59	....
1.00	96.0	523	11,326	837	13.5	14.77	1.094	21.6	1.60	....
2.00	94.5	509	11,418	809	14.1	15.32	1.087	22.4	1.58	11.72
3.00	95.5	498	11,300	826	13.6	14.66	1.078	22.9	1.65	10.63
4.00	96.4	537	12,251	845	14.6	15.84	1.085	22.9	1.56	11.65
FIVE-HOUR RUN, TUG RICHMOND (Aug. 24, 1903)										
12.00	..	...	.....	...	...	....	....	...	...	....
1.00	91	418	9,532	829	12.2	12.80	1.140	22.8	1.98	....
2.00	92	424	10,331	835	12.4	14.10	1.143	24.3	1.97	....
3.00	91	418	8,831	806	11.0	12.55	1.140	21.1	1.92	11.08
4.00	91	418	10,496	833	12.2	13.90	1.140	25.1	1.99	10.04
5.00	91	418	9,627	865	11.2	12.90	1.150	23.0	2.06	10.75
AVERAGE FOR FIVE HOURS RUN										
Payson —	95.5	520	11,553	834	13.8	15.05	1.089	22.2	1.59	11.15
Richmond —	91	419	9,743	833	11.8	13.05	1.142	23.2	1.96	10.47

From examinations of the logs of numerous steamships, it appears that with vessels fitted with triple-expansion engines de-

veloping from 1,000 h.p. up, with everything in first-class condition, the fuel consumption will be about 1¼ lbs. of oil per 1 h.p.-hr. For smaller vessels fitted with compound engines, the consumption will range from 1.6 to 2 lbs. per 1 h.p.-hr., depending on the efficiency of the plant.

Economic Advantages of Petroleum Over Coal as a Fuel for Steamships

a. The saving in labor and consequent reduction in the number of firemen. The amount of money saved varies with the size of the ship and the number of firemen carried. In installations of average size, one-third the number of firemen and coal passers necessary when burning coal would be sufficient.

b. Reduction in weight and bulk of fuel, giving increased cargo capacity and resultant greater earning power. Comparing "Wellington Screenings," a type of coal generally used for steamship work on the coast, and fuel oil at from 14 to 17 Baumé, oil for equal heating value occupies about one-half the space taken by the coal and has less than one-half the weight. Oil may be carried in parts of the ship not otherwise useful.

c. Saving in time. The time consumed in coaling and expense of moving to bunkers is saved, as fuel oil can be pumped into the ship when at the dock and while the cargo is being taken on or discharged.

d. Uniform steaming. The rate of steaming can be kept uniform, there being no loss due to cleaning fires, etc.

e. Cleanliness, due to the absence of coal dust and dirt when coaling and to the absence of ashes in the fireroom.

f. Reduced cost of maintenance. Fewer repairs on boilers due to uniform temperature in furnace and combustion chamber. No corrosion of floor plates, fire fronts, or bunkers. No grate bars to burn out, fire doors or ash-handling machinery to renew or repair.

A Comparison of the Economy of Powdered Coal, Oil and Water Gas for Heating Furnaces. C. F. Herington (Engineering News, Dec. 10, 1914) gives the following:

Oil. Of the 3 fuels, powdered coat, oil and water gas, fuel oil has come into use far more than any other. The U. S. Navy yards have been consistent in their adoption of it. All now use fuel oil for heating operations, many to the complete exclusion of coal.

Without a doubt, fuel oil is one of the easiest of fuels to handle; it can be carried in pipes anywhere so long as there is air pressure or pump pressure behind it. It requires only a comparatively small outlay for equipment — all that is necessary is a couple of storage tanks, a pump to fill the storage tanks from the cars, a piping system to the furnaces, and means to secure the necessary pressure.

But fuel oil has one disadvantage — and this is conceded by many to be a big one: the price is constantly going up. Ten years ago, fuel oil could be bought for 2½ cts. a gal., and one could contract for any quantity at that price; now it is 4½, 5 and 5½ cts. a gal., and one has to take what quantities he can get at that price. Present conditions indicate that this advance in cost will continue beyond the limits of economy.

Powdered Coal. Steady increase in the price of oil has led, quite recently, to extensive experiments in the use of powdered coal and of water gas and producer gas as substitutes. As a fuel for burning under boilers, powdered coal may some time be a success. The use of powdered coal in portland-cement manufacture has proven very economical and here it has come to stay. But when it is claimed that it is equally good for various heating operations, such as welding, shingling, annealing, riveting and forging, there is likely to be a difference of opinion.

In a recent article in an engineering paper, the following advantages were claimed for powdered coal:

(1) "Complete combustion, doing away with losses due to the carbon contained in the ash and in the escaping volatile matter." This is not correct, for if one stands for an hour watching one of these furnaces working, as the writer did, he will be completely covered with fine, unburned powdered coal which has escaped through the furnace doors. This has become such a nuisance to the surrounding machinery and workmen that attempts are now being made to relieve these conditions by placing a hood over the furnace door and connecting it into the furnace stack. This has not proven successful as yet, and probably will not until an exhaust fan is provided to discharge this unburned coal through the roof.

(2) "Total absence of smoke." Certainly this is not true inside of the shop, for powdered-coal furnaces, due to their ununiform feed, smoke worse than oil. Powdered coal, as is well known, must be very dry to be pulverized and, when pulverized and allowed to remain quiet for 48 hours, it cakes and requires that a man knock on the bins to loosen it. This leads to uneven combustion in the furnace with large quantities of smoke when there is a large amount of coal coming through the burner and no smoke when the coal is sticking back in the bins. No doubt this is largely due to inefficient handling of the feeder and burner; even so, a total absence of smoke cannot be claimed when such conditions are met.

(3) "A cheaper grade of coal may be used." The best coal for powdered fuel has a volatile content of not less than 30%, not more than 8% ash, and 1¼% sulphur. I think the readers will agree that coal meeting these specifications is of no very cheap grade.

Pulverized coal must be handled with great care, for if it is mixed with any quantity of air, it is highly explosive, as the records of accidents in cement plants will prove. In the January

issue of the Quarterly of the National Fire Protection Association, the following appeared regarding the hazards of drying pulverized coal:

"Under no circumstances is it recommended that the products of combustion be allowed to come in contact with the coal to be dried. . . . Already there have been quite a number of accidents from this cause in which lives were lost.

"A characteristic coal mill explosion (March 2, 1903), in New Village, N. J., at the Edison plant, killed six men and burned five others, perhaps fatally, besides injuring a score of others and destroying the coal building. It is supposed that the pulverized coal in bin fired spontaneously and some of the burning fuel was carried by the automatic conveyor into the blower house. The atmosphere of the blower house being charged with coal dust, an explosion was the result.

"On August 19, 1900, an explosion in the plant of the Nazareth Cement Co., Nazareth, Penn., caused a loss of $16,000, while on November 26 of the same year $40,000 damage was done to the Martin's Creek Portland Cement Co. (then known as William Krause Sons), Martin's Creek, Penn. The Dexter Cement Co., Nazareth, Penn., and the Alpha Portland Cement Mill No. 1, Alpha, N. J., had similar experiences the same year."

Another very serious objection to powdered coal, due to the incomplete combustion of all the coal ejected into the furnace, is that this coal lies on the work, and when the work is taken out of the furnace, if not cleaned off, it is apt to be hammered into the work and make flaws which later are likely to be more or less serious according to the nature of the work. This is a fact seen from personal observation and cannot be denied.

Powdered coal is not good for small furnaces, as it requires too large a chamber of combustion, and from the experience of the users of powdered coal it is not desirable to have a combustion chamber separated by a bridge-wall from the working chamber. It is found that the lesser of two evils is to remove the bridge-wall and blow the powdered coal directly upon the work, which aggravates the condition mentioned above. If the large furnaces are changed from fuel oil to powdered coal, there still remain the small furnaces, and especially the portable ones, which will have to work on fuel oil. Then there would be the expense of handling two kinds of fuel where before there was but one.

Gas. Greater familiarity and extended experience with natural gas for power and metallurgical purposes have led to better appreciation of the many advantages of gaseous fuel. It has emphasized the value of the gas producer for converting solid into gaseous fuels. But such conversion always involves a loss of a part of the energy of the coal; it is only because the gas can be utilized more efficiently that the duty obtained from it is greater than that given by the direct burning of the coal from which it is generated. Hence, any process which claims to deliver in the gas an amount of energy greater or even equal to that in the original fuel is a delusion or worse.

There are at present two kinds of made gases used for heating furnaces — producer and water gas. Industrially, producer gas is the combustible product of rather a complex series of physical and chemical changes induced in the fuel by the heat arising from its incomplete combustion in the producer. The combustion is termed incomplete not in the sense of leaving an unburned residue of carbon or coke, but because the combustible while completely gasified gives up only about 30% of its heat in primary combustion in the producer. The remaining 70% is developed when the gases are burned after leaving. Water gas is made by an intermittent process — first using an air blast to bring the fuel to high incandescence, then shutting off the air and forcing steam through the fire. During the air blow, a lean producer gas is made which may be enriched by the addition of water gas of a higher calorific value and used in the low-temperature furnaces or to drive gas engines. The true water gas is made during the steam blow, the steam being decomposed by the incandescent carbon so that its hydrogen is freed and its oxygen united with the carbon to form carbon monoxide.

The water gas can be used for all purposes where high temperatures must be secured without regeneration, as in factories carrying on a large variety of brazing, small forge work, etc., where the furnaces are small and distributed over a large area. Temperatures ranging from 2,500 degs. F. to 2,900 degs. F. are easily obtainable with this gas, and with properly constructed furnaces it is possible to gain an added efficiency in operation so that the total B. t. u. in the gas used need be only 66 to 80% of the B. t. u. required in oil as used in approved oil furnaces for the same purposes. Water gas does not cause the metal forged to scale as does oil, and with gas it is possible to get a closer regulation of furnace temperatures.

Comparative Efficiencies. Now comes the debatable point of what is the efficiency of the furnace when using the different fuels. The powdered coal advocates will claim that the efficiency should be figured on the B. t. u. basis. That is, if a furnace burns say 22 gals. of oil to do a certain piece of work and each gallon contains 140,000 B. t. u., 3,000,000 B. t. u. in all, it will take 3,000,000 B. t. u. in coal to do the same work, but the coal is cheaper. If oil were 5 cts a gal., it would take coal at $10 a ton to equal the cost; so the reader will perhaps agree that this is not the proper method of comparing efficiencies, any more than saying that the cost of gasoline per gallon is the operating cost of running an automobile.

The true way is to measure the efficiency of the furnace by the comparison of the input and output, and below are given results of some efficiency tests, made by the writer for a well known concern contemplating a revision of its furnace practice.

Powdered Coal. (Furnace using preheated air for combustion.)
Furnace cold at 60 degs. F.
Steel and furnace heated to 2,200 degs. F.
Rise in temperature, 2,140 degs. F.

By test, 6.29 lbs. of steel heated per lb. of coal burned.
Specific heat of steel, 0.117.
$0.117 \times 2{,}140 = 250$ B.t.u. per lb. of steel.
250 B.t.u. $\times$ 6.29 = 1,572 B.t.u. output.
1 lb. of coal = 14,000 B.t.u., input.

$$\text{Efficiency} = \frac{1{,}572 \times 100}{14{,}000} = 11.3\%.$$

Fuel Oil. Same furnace with same rise in temperature and the same charge of work.

Heated 8.68 lbs. of steel per pound of oil.
1 lb. of oil = 19,400 B.t.u., input.
250 B.t.u. $\times$ 8.68 = 2.170 B.t.u., output.

$$\text{Efficiency} = \frac{2{,}170 \times 100}{19{,}400} = 11.3\%.$$

Water Gas—(Furnace using preheated air for combustion).

1 cu. ft. of gas = 300 B.t.u.
Specific heat of wrought iron = 0.113 (Kent).
Temperature rise from 1,400 to 2,500 degs. = 1,100 degs. F.
Furnace charged with 3,800 lbs. iron.
To raise this iron to that temperature required 14,000 cu. ft. of gas.
$.113 \times 1{,}100 = 124$ B.t.u.
$3{,}800 \times 124 = 471{,}200$ B.t.u.
$14{,}000 \times 300 = 4{,}200{,}000$ B.t.u., input.

$$\text{Efficiency} = \frac{471{,}200 \times 100}{4{,}200{,}000} = 11.2\%.$$

Another furnace using fuel oil (not using preheated air).

Temperature rise from 1,200 degs. to 2,200 degs. = 1,000 degs. F.
Charge of wrought iron, 2,150 lbs.
Oil required, 22 gals.
2,150 lbs. $\times$ 113 B.t.u. = 242,950 B.t.u. output.
1 gal oil = 140,000 B.t.u.
140,000 B.t.u. $\times$ 22 = 3,080,000 B.t.u. input.

$$\text{Efficiency} = \frac{242{,}950 \times 100}{3{,}080{,}000} = 7.88\%.$$

First Costs. In making comparison as to the relative first costs and operating costs with the three kinds of fuel, let us assume a plant now using fuel oil with a consumption of 50,000 gals. of oil per month at a cost of 5 cts. per gal., delivered at the shop. (These estimates were made for the company already mentioned.)

FUEL OIL

Cost of equipment (storage tanks in place, auxiliary pressure tanks in place, piping and fittings in place, steam connections, furnace connections, tank-car connections, tank pumps and air-blast outfit)	$21,100
Contractors' profit (15%)	3,165
	$24,265
Engineering and contingencies (10%)	2,435
	$26,700

POWDERED COAL

Pulverizing machinery, house, foundations, trestle and track, electric wiring, conveyors, walkways, motors, burners and controllers (30), furnace bins (30), furnace changes, hoods and connections, etc.	$68,100
Contractor's profit (15%)	9,900
	$78,000
Engineering and contingencies (10%)	7,800
	$85,800

FUEL OIL FOR SMALL FURNACES

Tank in place, auxiliary tank in place, piping and fittings, furnce connections, tank-cars connections, pumps, air blast, etc.	$8,800
Contractor's profit (15%)	1,300
	$10,100
Engineering and contingencies (10%)	1,000
	$11,100

WATER AND PRODUCER GAS PLANT

Gas-making machinery, building, trestle and siding, piping, furnace changes	$76,000
Contractor's profit (15%)	11,000
	$87,000
Engineering and contingencies (10%)	8,700
	$95,700

SUMMARY

Fuel oil	$27,000
Powdered coal with fuel oil	97,000
Gas plant	96,000

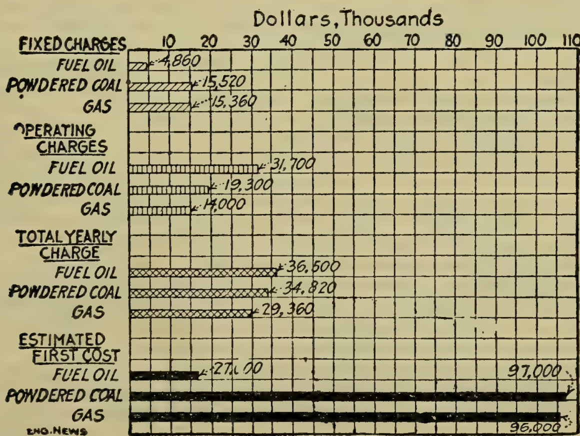


Fig. 7. Diagrammatic comparison of estimated first cost and annual charges of coal, oil and gas plants to supply fuel for 30 furnaces.

Fuel Consumption of Plants. For the fuel-oil plant, at 50,000 gals. of oil per month and 140,000 B. t. u. per gal., 7,000,000 B. t. u. are consumed per month. If we allow 10 lbs. of coal at 14,000 B. t. u., equal to 1 gal. of oil, we have 500,000 lbs. or 250 tons of coal used per month, for the powdered-coal plant. In addition, this plant consumes about 8,000 gals. of oil, the difference being compensated for by coal required in drying the main fuel supply. For the gas plant, we require about 60,000 cu. ft. of water-gas per hr., at 20 cu. ft. per lb. we require 3,000 lbs. of coal per hr. or 375 tons per month.

Now the total charges can be assembled.

FUEL OIL PLANT (estimated cost, $27,000).

Fixed charges:	
Interest (5%)	$ 1,350
Depreciation (12%)	3,240
Taxes and insurance (1%)	270
	$ 4,860
Operation:	
Oil (50,000 × 0.05 × 12)	$30,000
Labor, 1 man	1,000
Electrical current, steam, air	500
Miscellaneous supplies	200
	$31,700
Total yearly charge	$36,560

POWDERED COAL PLANT (estimated cost, $97,000).

Fixed charges:	
Interest (5%)	$ 4,850
Depreciation (10%)	9,700
Taxes and insurance (1%)	970
	$15,520
Operation:	
Coal (250 × 2.50 × 12)	$7,500
Oil (8,000 × 0.05 × 12)	4,800
Labor (1 operator, 2 assts.)	2,000
Electricity for motors	5,000
	$19,300
Total yearly charge	$34,820

GAS PLANT (estimated cost, $96,000).

Fixed charges:	
Interest (5%)	$ 4,800
Depreciation (10%)	9,600
Taxes and insurance (1%)	960
	$15,360
Operation:	
Coal (375 × 2.50 × 12)	$11,250
Labor (1 operator, 2 assts.)	2,000
Water	744
	$14,000
Total yearly charge	$29,360

These several figures are plotted on the accompanying diagram for easy comparison.

Oil and Coal Costs Compared. One ton (2000 lbs.) of coal is equivalent in practical heating value to 3.34 bbls. of oil at 325 lbs. The table below compares the prices of coal and oil for equivalent cost as fuel in a boiler furnace:

Coal, per ton (2,000 lbs.)	Oil, per bbl.		Coal, per ton (2,000 lbs.)	Oil, per bbl.	
$5.00	$1.50	$1.66†	$3.25	$0.98	$1.01
4.75	1.43	1.60	3.00	.90	1.00
4.50	1.35	1.50	2.75	.83	.92
4.25	1.28	1.42	2.50	.75	.83
4.00	1.20	1.33	2.25	.68	.75
3.75	1.13	1.25	2.00	.60	.66
3.50	1.05	1.02	...	..	..

* Not allowing for labor saving. † Assuming 10% of cost of fuel in labor of firing and handling ashes saved by using oil, a conservative estimate for plant of over 300 horsepower.

An interesting point to notice is that the heat value of an oil usually given is the high heat value, or heat value determined in a bomb calorimeter. The actual heat value available in a boiler furnace is less, because all fuel oil contains a considerable percentage of hydrogen, and the latent heat of the steam formed by the combustion of this hydrogen passes up the stack as waste heat.

In all the heavier grades of fuel, particularly the Mexican oils, water mixed with the oil is in the form of an emulsion and will not settle out in a tank, as it will with the lighter American crudes. This is not so much a disadvantage as it would seem other than causing a lowering of the heat value. With an oil light enough for the water to settle out of its own accord, this water will frequently accumulate in the tank and piping and go over into the burners in a slug, putting the burners out; but with heavy oil a very considerable amount of water can go through the burner with no bad effect. A small quantity of water in heavy oil is probably an advantage in that these oils are usually heated above the boiling point of water to effect atomization, and the vaporizing of the moisture in the oil as it leaves the burner tip probably helps to atomize the oil more thoroughly. (B. S. Nelson, Journal of the American Society of Mechanical Engineers, June, 1917.)

Fuel Values of Coal, Gas and Oil. E. H. Hunter and L. G. Purtee, operating engineers in Oklahoma, state in Electrical World, June 5, 1915, that about 10.5 cu. ft. of air is required for the combustion of 1 cu. ft. of gas. There are several good makes of gas burners on the market, but the secret of using most of them is in proper manipulation to get the right mixture of gas and air. To burn natural gas properly requires a furnace of somewhat different design from that used in burning oil. In some furnaces checker walls are used, while in others these walls are omitted entirely. There is considerable vibration in burning gas, as in oil, but this may be controlled to a considerable extent.

Comparing the 3 fuels as to value, said Mr. Hunter: At 212 degs. F., and atmospheric pressure, 1 lb. of coal will evaporate 9 lbs. of water; 1 lb. of oil will evaporate 15 lbs. of water, and 1 lb. of natural gas will evaporate 20 lbs. of water. Approxi-

mately 4,800 cu. ft. of gas equals a bbl. of oil, and 4.125 bbls. of oil equals a ton of good coal.

L. G. Purtee stated that gas as a fuel for the production of electric power is only a makeshift and a very expensive one. The only thing in its favor is the fact that it may be installed quickly and cheaply, used with a minimum amount of help, and has the advantage of cleanliness. But by the time the cost of a complete auxiliary oil-burning system and reserve supply of oil is taken into consideration the first cost is no small item and in the aggregate reaches a sum which would go a long way toward the installation of a mechanical coal handling and burning system, which would be permanent and by the use of which at least 25% better results may be obtained than is possible with gas.

Summing it up, Mr. Purtee offered the following estimates: $2.50 will buy 1 ton of coal containing 27,000,000 lbs. F. heat units; $2.50 will buy 4.5 bbls. of oil, containing 24,367,500 lbs. F. heat units; $2.50 will buy 25,000 ft. of gas, containing 22,500,000 lbs. F. heat units.

In other words, coal at $2.50 is 16⅔% cheaper than 10-ct. gas and 9.8% cheaper than 55-ct. oil. Fifty-five-ct. oil is 7.7% cheaper than 10-ct. gas, although operating conditions will usually make the final results of 55-ct. oil and 10-ct. gas practically the same.

Benzol as a Motor Fuel. The Journal für Gasbeleuchtung (Germany, 1915) quotes some particulars of substitutes for gasoline which, it states, have acquired importance as fuels for motor vehicles because of the scarcity of petrol in Germany. The consumption per horse power developed is approximately proportional to the calorific power of the fuels. The net calorific power in B. t. u. per lb. is given by Mohr for various fuels as follows: Petroleum spirit, 18,000 to 18,900; pure benzene, 17,208; commercial 90% benzol, 17,100 to 17,280; pure alcohol, 11,452; 95% alcohol, 10,575; pure naphthalene, 16,722. The following specifications for substitutes for benzol are given:

Benzol-Spirit. (*a*) 95% methylated spirit, 70 parts; benzol, 30 parts. The benzol is poured slowly into the spirit while stirring — not the spirit into the benzol. (*b*) 90%, or ordinary methylated spirits, 50 parts; commercial acetone or acetic alcohol, 20 parts; benzol, 30 parts. The spirit and acetone are first mixed, and the benzol gradually added.

Benzoline-Spirit. (*a*) 95% methylated spirit, 70 parts; benzoline, 30 parts. The benzoline is poured slowly into the spirit, stirring. (*b*) 90% or ordinary methylated spirit, 50 parts; commercial acetone or acetic alcohol, 20 parts; bezoline, 30 parts. The spirit and acetone are first mixed, and the benzoline added gradually.

Spirit-Ether. (*a*) 95% methylated spirit, 90 parts; sulphuric ether, 10 parts. (*b*) 95% methylated spirit, 90 parts; sulphuric ether, 10 parts, naphthalene, 1 part.

Acetone-Spirit. (*a*) 95% methylated spirit, 70 parts; commercial acetone, 30 parts. (*b*) 90% or ordinary methylated spirit, 50 parts; commercial acetone, 50 parts.

Petroleum Mixtures. (*a*) Petroleum and benzoline (petroleum spirit) mixed in proportion of 2 to 1. (*b*) Petroleum 3 parts, acetone 1 part. (*c*) Petroleum 90 parts, ether 10 parts, and 1 part naphthalene.

Oil Consumption of a Diesel Engine Ocean Vessel. The oil-engine cargo ship *Christian X* of the Hamburg-American Line is 370 ft. long, 53-ft. beam, 30 ft. deep, with a loaded draft of 23 ft. 6 ins. and a deadweight capacity of 7,400 tons. The twin screws are driven by a pair of 8-cylinder 4-cycle Diesel engines, aggregating 2,500 i.h.p. at 140 r.p.m. and there are two similar auxiliary engines of 200 h.p. at 225 r.p.m. The deck machinery, winches, windlass and steering gear are electrically driven. The ship was launched in March, 1912. The following account of its sea service is abstracted from a report published in The Engineer (London), July 18, 1913:

After loading in Hamburg for Havana, she commenced her first voyage on July 23, 1912, and until the vessel ran into Havana on Aug. 9, the engines ran at full power without any stoppage. The weather was very good, except for a couple of days when a fresh westerly wind raised a very rough sea, so that the propellers now and then came partly out of the water, causing the governors to come into action.

The fuel used was Roumanian oil. Its effective heat value was 17,800 B. t. u. The total consumption of fuel in 24 hrs.' trial was 8.545 tons (metric) for the main engines and 0.84 ton for the auxiliary engine. Thus the consumption per i.h.p.-hr. was: Main engines, including the oil used for the auxiliary machinery, 0.361 lb.; main engines, excluding the oil used for the auxiliary machinery, 0.328 lb.; the auxiliary engine, 0.357 lb. At Havana, the machinery was overhauled and found to be in perfect order, though the exhaust valves were changed and the oil valves were ground in.

The ship then proceeded to Vera Cruz. In August an easterly trade wind blows at about the same rate as the vessel's speed, and this portion of the voyage was hottest of the whole trip in the engine room, since the ventilators did not carry much air to the engineers' platform. The highest temperature was on Aug. 15. The temperature on deck in the shade was 89.6 degs. F., and that in the engine room 107.6 degs. F., or considerably less than the temperature in the engine room and the stokehold of a steamer under similar conditions.

From Vera Cruz the ship proceeded to Tampico, and took 100 tons of oil fuel, which was said to contain 1.72% of sulphur. The engines worked excellently with this oil, although the exhaust gases smelt very strongly of sulphur. On this account, in order to run no risk of damaging the machinery by the action of the sulphur, it was decided to continue the voyage on the Roumanian oil which was still left in the bottom tanks, until the other oil could be analyzed in order to make sure that the proportion of sulphur did not exceed 1.72%, which, of course, would be harmless.

The vessel left Coatzacoalcos Aug. 31 for New Orleans with

her holds empty. There it took a full cargo and left on Sept. 15, arriving at New York Sept. 19.

After filling the bottom tanks with fuel oil the ship left New York on Sept. 20 for the return to Hamburg. The next day there was a very strong head wind, the sea was very rough and the ship pitched and plunged heavily. The Aspinall governors worked without interruption as the propellers were thrown right out of the water. On Sept. 23 and 24 the starboard engine was put "half speed" to enable the ship to steer better against the high sea. On those two days the speed was only 6.26 and 8.41 knots respectively. On the 30th a storm commenced again from the northeast, and the engines had to be stopped for eight minutes to clean out the oil filters which were not then provided with by-passes. The constant rolling of the vessel set the oil in the tanks in such violent movement that the sludge or sediment had got down into the piping and had stopped up the filter entirely.

On Oct. 2 the very high sea smashed the railing on the promenade deck and bent all the awning posts on the port side. The starboard engine was afterward put to half speed so as to enable the ship to hold on her course, and the speed dropped to 5.9 knots. The vessel reached Hamburg on Oct. 6. The mean speed for the home voyage was 9.58 knots, a good result if bad weather and the head wind the whole way are taken into account. A summary of the voyage is shown in the accompanying table.

PERFORMANCE OF THE OIL-ENGINE SHIP "CHRISTIAN X" ON A VOYAGE OF 11,894 MILES

	Voyage days	Voyage hrs.	Dis-tance naut. miles	Speed knots per hr.	I. h.p.	Total tons	Oil consumed Per 24 hrs. tons	Oil consumed Kilos per i.h.p. per hr.
At Hamburg...	..	..	.....	....	....	14.02	...	....
To Havana	17	12	4,627	11.01	2,390	179.80	9.732	0.169
To Vera Cruz	2	19	810	12.11	....	38.75	10	....
To Tampico	0	17	210	12.54	....	10.28	...	....
To Coatzacoalcos..	1	3	311	11.38	....	13.28	9.50	....
To New Orleans..	2	10	698	12.10	....	33.68	9.80	....
To New York ...	5	5	1,613	12.92	....	58.60	9.90	....
To Hamburg	15	18	3,625	9.58	2,415	157.00	9.713	0.168
Total and average	45	12	11,894	10.89	2.440	505.41	9.75	0.169

On arrival, the engines were inspected and everything was found in order. Of the escape valves, which had been working since the departure from New Orleans, only two were attacked to such an extent that it was necessary to turn the valve seats. Notwithstanding the bad weather on the home run, the mean speed over the whole trip, outward and homeward, was 10.89 knots.

On the second voyage of the *Christian X*, which was made to New York and Philadelphia, things went well, and, notwithstanding very severe weather in the Atlantic on the outward trip, the average speed was 10.56 knots, while on the home run the rate was 11.41 knots.

On the third voyage, from the departure, on Jan. 6, a westerly

hurricane and wild sea had to be fought up to Jan. 15, and according to the engineer's log books, the Aspinall governors were working uninterruptedly. One of the life-boats, the after wheel-house and various fittings on deck were washed overboard, and it became necessary to slow down the engines in order to prevent everything being swept away by the heavy seas that constantly washed over the vessel.

In New York a new sort of oil fuel was taken on board which caused too early ignition with the engines going slow and the Aspinall governors at work, so that the valves hung open and some of them were spoiled. As there were only a few spare fuel valves, and as the captain did not think that he could hold the ship against the strong sea with a single engine in case of need, he preferred to turn and put into Queenstown, Ireland, rather than expose the vessel to further damage. On arrival in port the ignition was retarded by a simple operation, and the ship then went out on a trial trip which showed that all was in order. Spare valves were put on board and the vessel then continued her voyage toward Boston, where she arrived Feb. 15 without trouble, but again after experiencing very severe weather.

Fuel Oil for Steamships. The use of fuel oil for steamships has been constantly on the increase on the Pacific Coast, according to a recent Canadian Government report, largely because it is considered that 2 tons of oil will do the work of 3 tons of the best coal. The advantages in favor of oil are counted as having five main points: Great saving of time and labor in loading fuel; fewer men required for handling fuel on board ship; reduced cost of boiler and other repairs; increased cleanliness; and more complete combustion, and therefore greater efficiency of oil fuel. Recently many vessels have been altered so as to use either coal or oil fuel. Comparative costs of coal and oil on the *Princess Victoria*, operating daily between Vancouver, Victoria and Seattle, are given as follows:

COAL

	Per day
100 tons at $4.50	$450.00
9 firemen at $55 per month each	16.50
9 trimmers at $45 a month each	13.50
Food for 18 men	7.50
Total	$487.56

OIL

344.17 bbls. at 90 cts.	$314.25
6 firemen	11.10
Food for 6 men	2.53
Total	$327.87

Effect of Diesel Engines on Fuel Supply and Cost. S. A. Hadley of Kansas City, Mo., before the annual convention of Kansas Engineering Society, abstracted in Engineering and Contracting, Feb. 16, 1916, stated that the Diesel engine has not been introduced into this country long enough for the effect of its remarkable economy

to be perceived, though this economy has been proved and admitted. The cost of fuel, like everything else, is governed by the law of supply and demand, and Diesel engines will affect both.

The fuel supply of this country consists chiefly of petroleum and bituminous coal; natural gas and anthracite being sold now almost exclusively for house use are not affected much by the economy of the Diesel engines and will not be considered here.

The price of coal has increased about 1 ct. per ton at the mines each year in spite of increased production from 270,000,000 tons in 1900 to nearly 600,000,000 tons in 1915 on account of a demand which increased faster than improved methods of mining have cheapened the cost of production. Within the last 6 months the combination of an active demand, a threatened shortage and sympathy with the rise in oil prices has made a sudden increase of 15 cts. per ton, nearly 11% of the cost at the mine. It is believed that the cost of mining coal can not be further reduced, as increasing difficulties will more than offset improved methods. There is no large margin of profit to be absorbed and so the industrial growth of the country means constantly increasing prices for coal.

The Diesel engine which uses oil fuel will produce a brake horse power on 7,500 heat units in the fuel. Steam plants which now use coal almost exclusively for fuel require an average of 50,000 heat units per horse power ranging from 75,000 for the common factory or central station plant of less than 100 h.p. to about 20,000 for the best and most expensive large central station plants. Now much of the country is supplied with power by these smaller, less efficient steam plants where poor water supply or varying or insufficient load has prevented the installation of large steam plants of the better type. Here the Diesel engine can step in and make an immediate saving of about 80% of the fuel, for it is nearly as efficient in small sizes or at half load as in large sizes or at full load and is not affected by a poor or deficient water supply. Several instances in Kansas can be shown where small central station plants have reduced their annual fuel bill from more than $2,500 to less than $500.

The Diesel engine is limited in size to units of about 100 b.-h.p. and this might be thought to prevent it from competing with the large central station. To some extent this is true, but only in congested districts where power can be sold in large quantities with small distributing cost. There the coal fired steam plant of the latest design can produce the electrical energy at nearly as low fuel cost as with Diesel engine, because of the difference in the cost of heat units in coal and in oil. The investment in such a plant is nearly or quite as much as in the Diesel plant, being from $75 to $110 per k.w. exclusive of land or transmission lines. The convenience of having prime movers equal to the largest individual loads may warrant the use of steam, but where users of power are scattered over wider territory and no one unit requires several thousand k.ws. as may be the case in rolling mill work or electric smelting, electro-chemical processes such as obtaining nitro-

gen from the air by electrical discharges, etc., the Diesel engine can compete easily with the coal fired steam plant. Instead of central stations of from 5,000 to 50,000 capacity with step up transformers, high tension transmission lines, step down transformers and in the case of electric railways, rotary converter sub-stations, there may be a number of Diesel plants of 500 to 2,000 h.p. capacity each, equal to the sub-stations of the other system with generators producing current at moderate voltage, say, 2,300 to 3,300 in a.c. practice or 2,500 volts in the case of d.c. railway systems, and all these stations tied into one another in parallel operation. The investment would be less, the attendance no more, the plants could assist each other in emergencies by raising the voltage enough for two adjoining stations to carry the load of one temporarily disabled or cut down for any reason, the whole system would be more flexible and the economy of the Diesel engine could be realized at all loads. This method is possible because the Diesel engine is more efficient in units of 1,000 h.p. or smaller than the steam turbine plant in units of 25,000 h.p. and because power is finally used in relatively small amounts over a wide area and by producing it closer to where it is used the cost and loss of distribution is reduced. With high tension electrical transmission from large central plants, it must be transmitted twice, once at high tension to the sub-station and again at lower voltages back over practically the same ground to the user. The cost of distributing oil fuel to scattered Diesel plants is slight because of the small quantity and the fact that it can be piped or shipped in tank cars.

Electric traction has other advantages besides the saving of fuel and is being adopted on a large scale now, by the Chicago, Milwaukee & St. Paul Railroad to its mountain divisions where water power is available. The reduction in demand for coal caused by increasing use of Diesel engines may not result in decreased cost, but will at least check the increasing price and will allow more coal to be used for coke making, smelting ore, and for industrial processes that will benefit by a continued supply at a moderate price. Powdered coal is now being generally adopted for burning clinker in cement kilns, for brick and tile kilns, open hearth furnaces, etc. Increased prices for coal would be felt by these products and by all iron and steel makers, which take nearly as much coal to make the coke smelting ore as do the railroads.

The production of coke furnishes a source of fuel for the Diesel engines in the oil that can be distilled from coal tar. In Germany this fuel is used in preference to petroleum fuel oil, which is imported duty free. In this country it has not yet become a commercial reality as so much tar is used in the crude state for roofing, road building, paving, etc., but when we begin to refine the tar to obtain aniline dyes, fertilizers and other valuable by-products this tar oil will be produced in quantities sufficient to have a regular market and being a by-product will be sold at low price.

The increased demand for oil fuel can not raise the price much, for the engine uses the cheap heavy grades of crude oil which have little value for refining, and uses the residue after the gasolene and more valuable constituents have been removed. It is true that this by-product has risen in price lately almost 50% more than its low price of a year ago and there has been more than a doubling of price of crude oil, but a little consideration will show that further increases will affect the price of gasolene and the lighter products only as they have no substitute.

The production of crude oil for 1914 was 290,312,535 bbls. and for 1915 about 2,000,000 bbls. more. There was a decline in the last half of 1915 of almost 100,000 bbls. per day in the largest field, the Cushing, a decrease from the 1914 rate of 18,000,000 bbls., i. e., had Cushing kept its past rate the 1915 production would have been over 310,000,000 bbls. But this was the only field that decreased and many new wells were brought in and extensive new fields developed in Central Kansas and in Montana and it is expected these new fields will hold up production. The increasing demand which is raising prices is for gasolene and the heavy residue will remain a drug on the market except at prices which will compete with coal for boiler use in down town power plants and heating plants where its cleanliness and easy handling will allow it to be used at prices of from $1.25 to $1.50 per bbl. and probably a little higher. At these prices the Diesel engine can produce power to compete with coal in the ways mentioned before.

It remains to be seen how much of this comparatively cheap liquid fuel is available. Without taking into consideration the fuel oil that can, and undoubtedly will, be produced from coal tar, the supply is very large. Formerly over 50% and now about 20% of the crude oil, from the mid-continent field is marketed as fuel oil, though there is a wide variation with different oils and different refining companies. A much larger percentage of California and Mexican oil is fit only for fuel. In 1915 the production of the mid-continent field was 152,869,680 bbls., which by modern methods of refining yielded about 30,000,000 bbls. of fuel oil. California in 1915 produced 112,892,855 bbls. yielding over 50% of fuel oil or about 60,000,000 bbls. The total fuel oil supply for 1915 was 90,000,000 bbls. The above figures take account of modern methods of refining and by the older methods there will be much more fuel oil. There will probably be further changes in refining as the demand for gasolene grows. To offset this is the supply of Mexico which has just been tapped and is not now being imported at all in any considerable quantities. It is fair to assume that Mexico will at least supply enough to make up for a decrease in the production of fuel oil by improved methods of refining now unknown. It is a fact that the production of crude oil in the United States has increased steadily each year and that proved oil territory has widened. Some fields, notably the Cushing field, have fallen off in production, but none, not even those, are exhausted. It may be taken as an indication of the steadiness

of the supply that the Standard Oil Co. now have under construction 180 new stills in 7 different refineries.

Any builder of Diesel engines, of whom there are now a considerable number of good repute, will guarantee a brake h.p. on less than ½ lb of fuel oil. The annual production of 90,000,000 bbls. means 60 billion h.p.-hrs. or 20,000,000 h.p.-yrs. of 300 10-hr. days each. This is the amount of power now produced at an average of over 5 lbs. of coal per h.p.-hr., which can be had from Diesel engines, not taking into account the fuel oil from coal tar. It represents a yearly decrease in the demand for coal of 150,000,000 tons, one-fourth the present production, which will be that much added to our coal supply and will serve to prevent a rise in price. Our conclusion must be that the Diesel engine by its use of a by-product as fuel will defer the exhaustion of our coal supply and tend to maintain present prices and that without it there must be a considerable increase in fuel prices.

Types of Storage Plants for Anthracite Coal, Their Economic Features and Cost of Construction and Operation. R. V. Norris, in the Journal of the American Institute of Mining Engineers, 1911, by Engineering and Contracting, July 12, 1911, states that storage-plants vary much in detail of design, but may be generally divided into two classes — non-mechanical and mechanical storage — with the following types:

	NON-MECHANICAL	
(a) Level.	Stocking on the surface.	Reloading by hand or steam-shovel.
(b) Level.	Stocking from trestles.	Reloading by hand or steam-shovel.
(c) Level.	Stocking from trestles.	Reloading by tunnel with or without dock-scrapers.
(d) Level.	Stocking in bins.	Reloading by tunnels.
(e) Level.	Stocking by cable-railway and dump-cars	Reloading by hand or from bins.
(f) Hillside.	Stocking from trestles	Reloading by hand, scrapers, or hydraulicking.
	MECHANICAL	
(g) Hillside.	Stocking by traveling-cantilever trimmer.	Reloading by hydraulicking.
(h) Level.	Traveling or fixed tramways.	Stocking and reloading by traveling buckets.
(i) Level.	Dodge system. Stocking by truss-trimmers in conical piles.	Reloading by swinging conveyors.
(j) Level.	Stocking by traveling trimmer.	Reloading by tunnel and traversing-conveyors.
(k) Level.	Covered plants. Stocking by fixed trimmers.	Reloading by traversing-conveyors or by tunnel and dock-scrapers.

The line between the non-mechanical and the mechanical types is hard to draw, so many plants being combinations of both types. We have taken as mechanical storage, all plants using machinery

in storing coal, and as non-mechanical those storing by dumping, without regard to the occasional incidental use of machinery for reloading in some of the non-mechanical plants above described.

Dump-Storage (Non-Mechanical). The simplest method of stocking large volumes of coal consists in forming a dump on a fairly-level surface, laying temporary tracks on the accumulating stock, and raising and shifting these as the storage grows in extent and height Reloading is accomplished either by steam-shovels or grab-bucket cranes, operated from the edges of the pile from tracks which are shifted as reloading progresses. This plan is only suitable for temporary storage of steam sizes. Only one size can be stored, the breakage is excessive in any event, and prohibitory with prepared sizes, no rescreening is possible, and the cost of operation, not including waste, approximates 20 to 25 cts. per ton handled.

Trestle-Storage (Non-Mechanical). A method of storage now in general use in retail yards, and also attempted on a larger scale, consists of a trestle of the height of the proposed top of the pile, over which the loaded cars are dumped, forming a long pile of usually only moderate height, sizes being separated by partitions. Reloading is accomplished usually by hand. Trestle storage is small in capacity for the cost, expensive in operation, high in breakage, and is generally costly and inefficient; it does, however, permit the storage of various sizes. Its use should be confined to small retail yards, used for transport to proper screens for final reloading.

Trestle and Tunnel Storage (Non-Mechanical). A more efficient type of trestle-storage unites, with the trestle-stocking, the provision of a tunnel under the trestle for reloading. The coal is fed into cars in this tunnel through gates, and the cars may be either regular railroad equipment or narrow-gage dump-cars. Breakage is excessive, including not only that incident to the trestle-storage, but to drawing at least a portion of the coal from the center of the pile under pressure. Except with the use of separate screening-plant, no rescreening is possible; and further, less than 60% of the coal is tributary to the tunnel by gravity, and the two outlying wedge-shaped piles must be transported to the tunnel by hand, or better, by the use of dock-scrapers, which are also occasionally used for extending the storage beyond the gravity-range of the trestle.

Bin-Stocking (Non-Mechanical). In general, the construction consists of wooden bins traversed by railroad tracks from which the various sizes and types of coal are dumped, each in its appropriate bin. Reloading is usually accomplished by cars passing under the bins, either on the surface or more frequently in tunnels. To reduce the danger from fire, the movement of the reloading-cars is usually by gravity or by rope-haulage. The individual bins are necessarily limited in capacity to from 50 to 100 tons each, and an extensive plant covers a very large area. One such plant at the seaboard has 384 bins, reloading into cars in 9 tunnels, and covers approximately 9 acres. Such a plant costs in excess of $3 per ton of capacity to erect, requires an enormous amount of

timber, with resulting large fire-hazard and high maintenance charges, and the operating expenses approach 10 cts. per ton.

A great advantage is the practicability of storing many sizes and kinds of coal, and keeping separate many small consignments. The breakage in this type of plant is very serious. The loss at seaboard on 1,000,000 tons of prepared and pea coal in about the usual proportions, would amount to $545,000, or 54½ cts. per ton, in addition to the cost of storage.

Cable-Railroad Storage (Non-Mechanical). A modification of the bin and tunnel type involves the use of cable or gravity return cars, running out on trestles over bins or surface storage, and dumping their contents at the desired points. This type is used at many retail yards and at transfer points, especially where water-borne coal is transferred to yards or cars The plant is moderate in first cost, economical in operation, but high in breakage; does not permit rescreening except as a separate operation, and, being of timber, is subject to destructive fires. It does, however, lend itself readily to covering for weather protection.

Hillside Storage (Non-Mechanical). Given a not impracticable hill, a plant consists essentially of one or more dumping tracks at the top, which in the older forms of plant are necessarily on rather high trestles. The coal is dropped from these trestles (the fall being broken as much as possible by chutes) and spreads down the hillside until arrested by walls, barriers, or by a level space at the bottom. But little coal can be reloaded directly by gravity except the layer which may be held by a retaining wall at the bottom, so it is usual to reload by hand, or better, by the use of dock scrapers or swinging conveyors along the level space at the bottom of the plant.

In one large plant almost all the coal is put into a conveyor at the foot of the hill and scraped to a central screen house, where it is thoroughly rescreened and all the sizes recovered. In other cases reloading is done over fixed or shaking screens placed at intervals above the tracks, and the screenings from these are taken by cars or conveyors to a small screen house for separation. In many cases the difficulty of handling at the foot of the hill is solved by the use of hydraulicking water, best heated in winter, which is used under considerable pressure to carry the coal to the conveyors or cars for reloading. This solves the problem of frozen coal as far as the storage plant is concerned; but arrangements must be made for the disposal of the water, and in winter shipments the coal reaches its destination frozen.

Where various sizes are stored it is necessary to provide partitions between the sections. These usually take the form of fences of heavy planking supported by large vertical posts, and braced by a forest of props. The downward motion of the coal has a strong tendency to dislodge these supports, with resultant heavy maintenance cost. Moreover, to avoid admixture of dirt with the coal, it has been found necessary to protect the entire hillside, either by paving, planking, or concrete. This is particularly necessary where water is used in reloading.

The cost of installing a hillside storage plant of this type is about $1.60 per ton of capacity complete, including railroads, trestle, partitions, water supply, conveyors, screen house and planking. With concreted or paved hillside the cost would probably be a little higher. The operating cost, exclusive of fixed charges and deterioration of coal, but including labor, repairs, power, and shifting cars, will approximate 10 cts. per ton for the coal passed through storage, dependent, as in all cases of storage operating cost, on the activity of the plant. The breakage of coal is somewhat large.

From the above it appears that the non-mechanical plants are generally expensive, both to erect and to operate, do not generally lend themselves to the necessary screening, and involve a serious breakage of coal. On the other hand, they are suitable to small quantities of storage, lend themselves to separation of sizes and qualities, and are in general suitable rather to retail yards or the smaller type of wholesale piers than to extensive storage.

Mechanical Storage Plants

Hillside with Mechanical Stocking (*Mechanical*). The most notable plant of this type was constructed during 1905–6, for the Lehigh Valley Coal Co., at Hudsondale, Pa. Owing to the high breakage loss in prepared sizes in hillside storage the plant was designed and is operated exclusively for the storage of small sizes.

The hillside selected was fairly straight and true in grades, but required heavy earthwork for the reloading tracks, and the stocking track at the head of the hill was inaccessible at reasonable grades with prohibitory cost, and is reached by an engine plant. The plant (Fig. 8) differs from all previous hillside plants in many particulars. Owing to the configuration of the ground the loaded cars are hoisted up a plane 500 ft. long on a 30% grade, by a pair of 18–30-in. hoisting engines, double geared 16 to 1 to a 10-ft. drum. The cars are pushed up by a steel barney, which returns into a pit at the foot of the plane. From the head of the plane the cars run over a double track trestle just high enough to permit dumping the coal into a traveling cantilever trimmer, by which it is elevated and discharged on to the concrete floored hillside, making a pile more than 55 ft. deep at its maximum, tailing down against a concrete retaining wall extending 7 ft. above the storage floor. This wall has a total height of 24 ft. above the reloading tracks, and is provided with openings on 20-ft. centers discharging the coal over screens directly into railroad cars for shipment. The screenings are washed in a trough to a small screen house at the lower end of the plant, where they are rescreened for shipment. As but a small portion of the coal is accessible by gravity, the main reloading is done by the use of water pumped from a nearby creek to a storage tank on the hill above the plant, and used with hose streams to wash the coal to the gates and over the screens.

Railroad cars are handled by gravity on both reloading and

stocking tracks, and the empty cars from the latter are lowered on a plane, operated by a drum with powerful air brakes, to the level of the railroad.

Except the hoisting engines for the loaded car plane, the entire

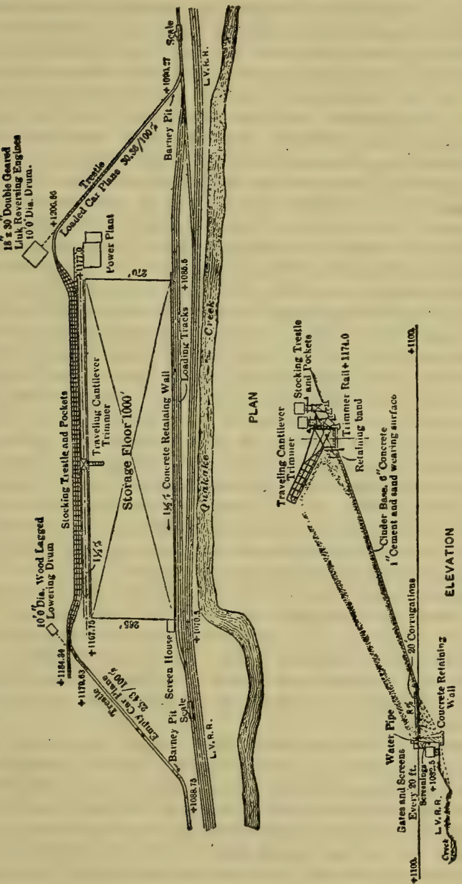


Fig. 8. Hillside storage plant, Lehigh Valley Coal Co., Hudsondale, Pa. Plan and cross section.

plant is electrically operated and lighted from a station included in the equipment.

The two tracks on the dumping trestles are at different elevations, to minimize the drop at this point, and the chutes under

these form a shallow pocket controlled by numerous gates. This pocket, while not of a depth to increase the drop from the hoppers of the cars, has sufficient capacity to give the trimmers a continuous supply, regardless of the variations in discharge in unloading and moving the cars. The cantilever trimmer consists of a platform traveling parallel to the dumping trestle on a 16-ft. gage track and carrying a cantilever truss equipped with a scraper conveyor. Except the drop from the cars to the chute immediately below and just clearing the hoppers, the only other drop involved in storing coal is in making the first small pile behind the bulkhead. After this reaches the line of trimmer the pile is filled by moving the discharge outward, and the coal from the end of the trimmer reaches the growing pile without appreciable drop, and extends the pile by avalanching, as previously described.

The storage floor averages 200 × 1,000 ft. on the hillside. This was first traced to squares 25 ft. on a side, so designated to give the best slopes without re-entrant angles, attainable without too serious grading. The floor thus prepared was covered with from 2 to 3 ft. of cinders, placed by the use of a temporary cable way, and then with 6 ins. of cinder-concrete with a wearing surface of 1 in. of cement and sand. The entire preparation of the floor cost a little less than 26 cts. per sq. ft., of which nearly 14 cts. was for the concrete. The lowest 30 ft. of the floor is on a much flatter grade than the rest, and with a view to a better conduction of the water and coal over this section the floor is made with 20-ft. corrugations, the bottom of each leading to a gate. Experience has proved the advantage of this arrangement, and further, that it would have been very advantageous to carry these corrugations the entire width of the floor, as considerable difficulty is encountered in washing down the fine coal by reason of the spreading of the water. In many cases in reloading the coal temporary iron chutes are laid to prevent this spread.

The retaining wall was built of concrete reinforced with old wire rope, with an aggregate of crushed mine refuse; this, by reason of its character, has somewhat deteriorated the concrete, and the wall, while designed amply against overturning, and anchored back by numerous tie-rods, has been forced forward to some extent in places, probably by the freezing of water in the fill behind it.

The problem of letting down the loaded cars was solved by the use of a second plane, single track, with a barney ahead of the cars disappearing at the bottom into a pit. The controlling drum lowers by means of a band-brake on an asbestos-lined brakewheel, operated by a standard Westinghouse air-brake equipment, supplied with air by an automatic electrically driven air pump. The barney is hoisted by a small motor, clutch connected to a train of gearing operating the drum, and runaways are guarded against by a governor, which sets the brake in case a safe speed in lowering is exceeded. The brake is also arranged for hand-operation in emergency.

Different sizes when stored are either separated by temporary

bulkheads or the edges of the piles are allowed to mix, the sizes being separated by the shipping screen.

As this plant is used (and is suitable) only for the small sizes of coal, the question of breakage is not of supreme importance, and no accurate figures are available as to its amount. From observation I would consider it small, probably not much exceeding that in a standard Dodge plant. The entire cost including all charges approximated $1.50 per ton of capacity, and when in active operation the handling cost has reached the record figure of 1.25 cts. per ton handled through the plant.

Traveling or Fixed Tramway Storage (Mechanical). The tramway type of storage, stocking and reloading by traveling buckets, while in very general use for ore-storage, has been but little used for stocking anthracite on an extensive scale, largely on account of excessive breakage, the impracticability of rescreening before reshipment, and small handling capacity.

The largest plant of this type for anthracite storage was built for Coxe Bros. & Co., at Roan Junction, Pa., with a capacity of 100,000 tons in a continuous pile, since increased to more than 150,000 tons. This plant consists essentially of a traveling truss, 225 ft. span, with 100-ft. cantilever-extension and 40-ft. back-projection. The truss is 55 ft. high above the rail at the traveler, and the bottom member has an elevation of 40 ft. above the storage ground. The truss is supported by a tower, spanning the reloading tracks and containing the engines and boiler for operation. The outboard end, supported by an A-frame, travels on a single rail, outside of which the stocking track is elevated to such a height that cars can be dumped into small hoppers, 50-ft. centers, from which the coal is drawn into 5-ton buckets, supported on traversing truck. One bucket is hoisted, carried along the truss, lowered, and dumped on the stock pile while its companion is being filed; these buckets dump automatically only when resting on the stockpile. Reloading is accomplished by the use of a 3-ton "shovel bucket," which is filled by pulling it over the surface of the coal, and dumped by hand into cars at the reloading tower.

While a large storage at low cost per ton is attained, the handling capacity of the plant is small, the average rate of stocking is but 83 and of reloading 70 tons per hour, woefully insufficient for a plant of this capacity. This condition could, of course, be remedied by the use of several trusses, which, however, would greatly increase the cost of installation. The breakage, particularly in reloading, is heavy, and on this account the plant is chiefly used for the smaller sizes. The original cost of construction is said to have been but $60,000, or 60 cts. per ton of rated capacity. The present cost would be at least 50% greater. The cost of operation averages slightly over 5.5 cts. per ton for stocking and about the same amount for reloading on a total exceeding 150,000 tons handled, including all labor, repairs, and train service, but not interest charges or depreciation of plant.

An interesting plant of this type is situated at Fall River, Mass. The plant consists (Fig. 9) of a traveling tramway, with cantilever

extension over the pockets and hinged bridge extension to extend over the barges. The tramway is hung from its supports by a number of thin eye-bars, giving flexibility sufficient to permit of swinging 11.5 degs. either side of the center line, allowing a variation of 50 ft. each way over the pockets, which is necessary to permit of the selection of pockets for various sizes of coal. Unloading, both from the barges and from stock, is done by means of a 2-ton clam-shell bucket, in which coal is carried to the desired point, lowered, and let out either on the storage pile or in the pockets, which are large enough to receive it. The plant handles

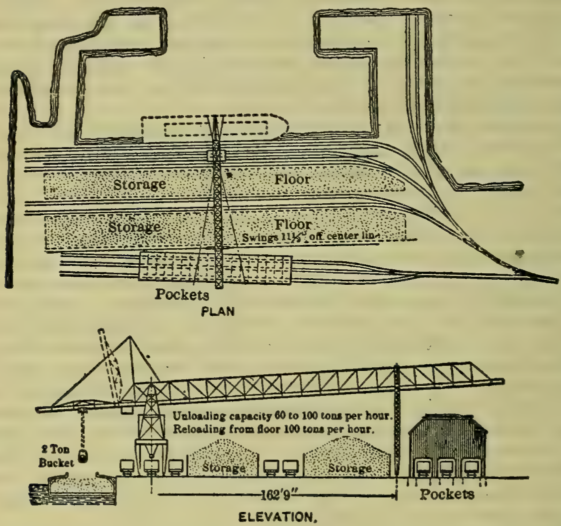


Fig. 9. Travelling tramway storage and handling plant, Staples Coal Co., Fall River, Mass. Plan and elevation.

both anthracite and bituminous coal, as may be required and in reloading from stock the tramway is assisted by a locomotive crane with clam-shell bucket of 0.5 ton capacity.

The cost of operation in the plant has been reduced to about one-third of its previous cost. The total cost of the plant was about $50,000, and the saving by its use exceeded 10 cts. per ton on 150,000 tons handled per year, besides reducing the screenings from 7 to less than 4%. The guaranteed speed of operation is 100 tons per hour, which rate in practice has been nearly doubled in emergency.

In general the tramway system, within its limitations, is probably the lowest in first cost of all the storage systems, while the operating cost is between that of the non-mechanical and the

large mechanically operated plants. The principal advantages of this type are low first cost, flexibility, moderate labor cost and repairs; the disadvantages, large space occupied by reason of relatively low piles, danger from wind, excessive breakage (from the tendency of the operators to dump the buckets without lowering to the stock pile), and lack of facilities for rescreening in loading out from stock.

Dodge Storage System (Mechanical). The Dodge system fills more nearly than any other the conditions of an ideal plant. In its standard form, Fig. 10, anthracite is stored in conical piles by means of a trimmer truss carrying a flight conveyor, with a movable bottom, which discharges at the apex of the growing

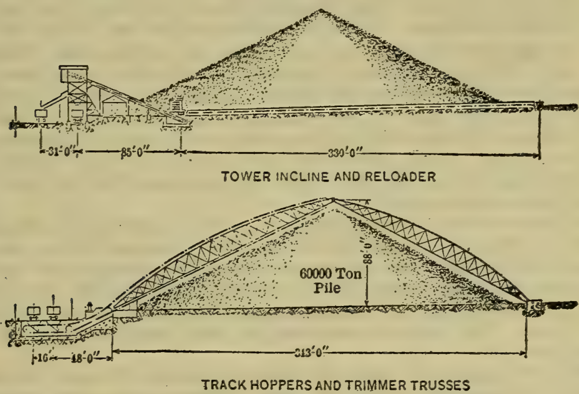


Fig. 10. Standard type of Dodge storage plant.

conical pile, and reloading is accomplished by a horizontal swinging truss, placed between two conical piles, carrying on its edge a flight conveyor. This conveyor takes the coal from the edge of the conical pile, draws it to a central point, and by a change in direction carries the coal up an incline to a tower, in which it is thoroughly screened on its way to the car.

The trimming conveyor is supported by a light hinged arch truss of span suited to the size of the pile, with a pitch equal to the angle of repose of the coal, carrying in its bottom member the trough-and-chain conveyor, which returns over the top. The bottom of the trough is a single movable strip of sheet steel wound on a drum at the foot of the truss and pulled by power up the truss, advancing as the pile grows, leaving an open bottom above the point of discharge, thus minimizing the breakage at this point, as the coal is merely shoved out on to the point of the conical pile and builds the pile by avalanching rather than by rolling. The thrust of the arch-truss is taken up by tie-rods extending

under the storage floor, and wind-pressure is provided for by guy-ropes extending above the surface of the coal to anchorages outside the piles. The trimming conveyor extends from the foot of the truss on a catenary curve to an extension under the dumping tracks, where hoppers are provided, feeding the conveyor to capacity by adjustable gates.

Two trimming trusses with respective track hoppers and a central reloader form a unit of construction.

The reloader is pivoted between the two piles, and swings on curved supporting tracks, just clearing the outer ends of the trusses, and covers both floors, leaving only a small crescent-shaped pile outside its reach on each floor. These piles are handled either by hand or by dock scrapers to within reach of the end of the reloader. The reloader-truss, carrying the moving conveyor on its faces, is fed by power against the bottom of the pile, being operated from a station on the pivot, from which a full view of the operation is assured. As the piles cone down by avalanching, and not by continuous rolling, it is often necessary to back out the reloader in a hurry to avoid having it buried. The movement is accomplished by wire cables which lie along one of the circular tracks under the coal, and the ends of which coil on reversing drums in the engine house, controlled by clutches from the operator's platform.

At the pivot-end of the reloader the chain carrying the conveyor-flights is deflected up an incline to the reloading tower. In the case of the largest piles, the strain from this extension has proved too great for the Dodge chain necessarily employed in making this turn, and separate conveyors are installed on the reloader and tower. The reloader-conveyor in this case transfers to the tower-conveyor.

The reloading tower contains shaking screens of ample capacity to fully rescreen the coal, and after passing over these the coal goes by a chute to the cars for reshipment. These loading chutes are long and originally caused considerable breakage, but the later ones are covered and provided with an end-gate, by means of which the chutes can be kept full and the coal poured from the end without the velocity which would be acquired in a free slide for the length of the chute.

The screenings are collected in hoppers in the towers, and in modern plants they are taken to a separate screen house for repreparation into marketable sizes, either by long conveyors or by cars, with rope or locomotive haulage.

Power is provided for the operation of each unit from engines or motors in a house adjoining the reloading tower. The trimmer conveyors, while occasionally driven by motors at the top of the trusses, are usually operated by rope-drives from the engine house to the head sheaves on the trusses, with the object of minimizing the weight on the truss.

It is evident that but one size and kind of coal should be stored in any one pile, and this limitation, involving the installation of numerous piles, is the most serious objection to the system.

The approximate cost of the machinery and trusses, per ton of capacity, varies greatly with the size of unit-piles. The following is a table of approximate costs:

Capacity tons	Diam., ft.	Height, ft.	Cost per ton
120,000	333	85	$0.6625
100,000	313	80	0.72
80,000	293	74	0.8125
60,000	263	67	0.995
50,000	248	63	1.08
40,000	230	58½	1.265
30,000	208	53	1.54

This is for plants of 2 units. To this amount must be added the cost of foundations, track-hopper pits, preparation of floors, central power plant (steam or electricity) and power-distribution, drainage, screen-house for screenings, and railroad tracks, scales and yards.

The most modern plants have been built of great capacity, with large unit-piles of from 50,000 to 60,000 tons' capacity, with the result of reducing the first cost of a complete plant from $1.50 per ton of capacity for a 300,000-ton plant, with 25,000-ton units, to $1.06 per ton for a 480,000-ton plant, with 60,000-ton units. Depending upon the size of units, the handling capacity varies from 50 to 150 tons per hour for stocking or reloading, which speed is attained easily in actual work, including the time lost in spotting and opening the hopper-bottom steel cars.

Owing to the thorough rescreening in use, the breakage in handling by this type of plant is quite accurately known. In the operation of a typical modern plant the following breakage calculation from cleaned-up piles has been recorded. The amount screened out as smaller sizes is as follows:

Size stocked	Stove, %	Nut, %	Pea, %	Buckwheat, %	Rice, barley and dirt, %
Egg	8.9	2.4	0.58	0.50	1.82
Stove	..	3.9	0.93	0.65	0.37
Nut	..	..	1.40	1.10	0.36
Pea	..	..	...	1.01	0.37
Buckwheat	..	..	...	...	0.56

This loss, figured on 1,000,000 tons of assumed quantities of each size passing through storage, is $53,561.25, or 5.36 cts. per ton.

The cost of operation, fairly averaged at 5 cts. per ton handled each way, is extremely variable, dependent upon the activity of the plant. For a large tonnage it has been as low as 2.4 cts. per ton, and for three consecutive months it averaged 4.6 cts. per ton, including all labor, repairs, and supplies, but not interest, taxes, or depreciation, with occasional jumps to 35 cts. or 40 cts. per ton during inactive times when but little coal was handled and the fixed charges for attendance dominated the cost.

An essential feature of this type of plant is ample railroad trackage. A plant of 500,000 tons' capacity will be nearly 1.5 miles long, and will contain in the aggregate about 10 miles of tracks.

The power required to operate a plant of this type was determined for a 60,000-ton unit, two 30,000-ton piles, at the McClellan plant of the Susquehanna Coal Co., to be:

	I. h.p.
Engine and attached machinery, light	15.5
No. 1 trimmer-conveyor, empty	37.0
No. 1 trimmer-conveyor, loaded	53.5
No. 2 trimmer-conveyor, empty	36.7
No. 2 trimmer-conveyor, loaded	53.3
Reloader-conveyor, empty	38.7

In the screen house and on the towers, each shaking screen, 6 × 12 ft. in size, required 2.62 h.p. for operation. At the time when this test was made reloading was not in progress, so no test could be made on the reloader actually in service.

The most recent plant of the standard Dodge type was erected in 1907–08, for the Lehigh Coal & Navigation Co., at Hauto, Pa. The detailed costs of this plant are available through the courtesy of W. A. Lathrop, president, and Baird Snyder, Jr., general superintendent of the company.

The plant consists at present of four 30-000-ton and two 60,000-ton piles, total capacity 240,000 tons, arranged in line on one side of the tracks, the other side being reserved for extensions. At the present time two more 60,000-ton piles are being erected, increasing the capacity to 360,000 tons, which should be available early in the summer.

Special features of the plant are electrical driving from the central station of the Lehigh Coal & Navigation Co., at Lansford. Each unit, two piles with pivoted reloader, is driven from its own power house; the transmission to the trimmers, reloader, and loading-tower of each is by rope-drives. Each loading-tower is equipped with a shaking-screen, 5 × 12 ft. screening surface, provided with a full set of perforated plates for any size of coal. The screenings are washed in troughs to a very complete screen house at the lower end of the plant. Sufficient grade for this washing is obtained by the use of 2 elevator towers in the line of troughs, which by raising the screenings avoid undue elevation of the troughs.

The screen house is provided with breaking-down rolls and a full set of screens for separating the screenings into sizes, which are shipped directly from the screen house pockets.

The site selected is a favorable one for this type of storage. No excessive grading was required, and drainage is available, so that it is the practice to use water for reloading frozen coal.

As in all plants of this type, the capacity of the piles is rated on the assumption of strictly conical structure, built directly by the trimming conveyors, while in case of necessity the piles can be materially extended by the use of sheet-iron chutes from the head of the trimmer. In this plant such extension has been carried to the limit by the further use of plank bulkheads between the piles, so that a rated 30,000-ton pile of egg coal actually contained 70,600 tons, more than 135% above its rated capacity. The bulk-

heads are built with a face of 2-in. plank, retained by cleats of plank extending into the body of coal and held against spreading by the friction of the coal itself.

The cost of the present 240,000-ton plant complete was $415,771.70, or $1.732 per ton of rated capacity, made up of items as follows:

		Per ton of rated capacity
Grading and masonry	$ 94,996.49	$0.395 —
Railroads	32,656.84	0.136
Buildings	26,070.54	0.108 +
Machinery	215,766.73	0.900 —
Electric installation	15,829.81	0.066
Screen-house	28,415.37	0.119 +
Electric power-transmission	2,035.92	0.008
	$415,771.70	$1.732

The two 60,000-ton piles now under contract are estimated to cost $120,000, which will make the entire cost of the 360,000-ton plant $536,000, or $1.49 per ton of rated capacity.

The cost of operation for the first year only is available, amounting to 209,690 tons handled to $9,263.59, or $0.0442 per ton, as follows:

	Amount	Cost per ton
Superintendence	$ 584.62	$0.00279
Labor	3,541.48	0.0169
Supplies	1,536.39	0.00732
Repairs	80.68	0.0003
Electric power	1,133.67	0.0054
Cost	$6,876.84	$0.0328
Transportation	2,386.75	0.01143
Total cost	$9,263.59	$0.0442

In general this type of plant combines most of the qualifications of an ideal plant; its main disadvantages are: (1) the large individual units, with consequent tying up of capacity when but a small amount of coal of a particular size or kind is to be stored; (2) expensive operation in the case of frozen coal, with liability to this difficulty from the method of making the piles. The coal can be handled with hot water if a supply is available, but this requires extensive drainage. This type is suited either to very extensive storage of hundreds of thousands of tons, or for the storage of moderate quantities of a single size, as for large steam plants.

The Ransom Storage System (*Mechanical*). A notable variation from the Dodge type was built for the Lehigh Valley Coal Co., at Ransom, Pa. The type of plant erected, Fig. 11, varies from the standard Dodge type in the use of a traveling trimmer-truss, building a wedge-shaped pile of coal with rounded ends, and reloading by conveyors in tunnels, with the assistance of traveling reloaders, to a central loading tower and screen house.

The cost of the plant complete, including machinery, power

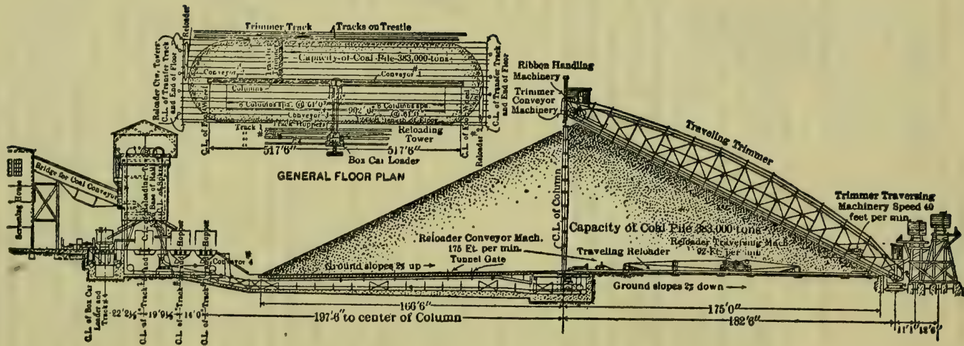


Fig. 11. Ransom plant, Lehigh Valley Coal Co. Plan and cross section.

equipment, grading, tracks, reloading and transfer tower, screen house, dam, and a 0.5-mile pipe line for water supply, trestles, rope haulage, and lighting, was very close to $1.15 per ton of capacity, and the operating expense, excluding interest, taxes and depreciation, is reported as low as 1.75 cts. per ton handled during months of active operation. No reliable data from a full clean-up are available as to breakage, but this appears to be somewhat greater than in a standard Dodge plant.

The plant as a whole has the advantages of low first cost, cheap handling, large storage for the area occupied, ease and cheapness of extension, exceptionally thorough rescreening and ease of preparation of the screenings, low repairs, moderate maintenance, and very rapid handling. The disadvantages are inherent to the type: impossibility of handling more than one size at a time, in either stocking or reloading; partial mixing of sizes, except at a great sacrifice of capacity; limitation of number of sizes to not exceeding four; some fire danger; and high depreciation on the wooden trestle.

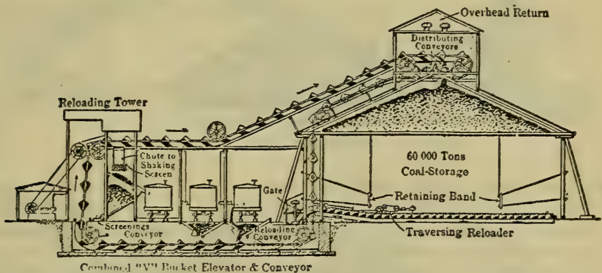


Fig. 12. Erie Railroad covered storage and transfer plant, Hammond, Ind. Cross section.

Covered Storage Plants (Mechanical). The difficulties from frozen and snow-covered coal, which are annoying in the latitude of New York, become so serious in more northern regions as to warrant expensive arrangements for their avoidance. As mere cold involves no difficulty in reloading, trouble from freezing is cured by the use of covered plants.

The Hammond, Ind., plant of the Erie R. R. (Fig. 12) of 60,000 tons' capacity, a building 840 ft. long by 90 ft. wide, stores coal by a conveyor system, with cross conveyor in the roof. The sizes are separated by A-partitions and the walls sustained by anchor-bands in the coal itself. Reloading is accomplished by running the forward coal by gravity into a longitudinal conveyor in front of the building, whence it is transferred to the return-buckets of the storing-conveyor, elevated to the loading tower, screened and shipped. The screenings are prepared in a separate building. The balance of the coal in each pocket is delivered to the front

conveyor by traversing Dodge reloaders, one serving each two bins. These are sheltered under the A-partitions when the bins are full. This plant, which also is used as a transfer plant, has the advantage of covered storage, moderate cost under the conditions, good handling capacity and rescreening, with, as its most serious objections, fire risk and excessive breakage from transfers between conveyors, and drop from the roof of the building in storing coal.

A better type, also designed by the Dodge Co., and erected for the Lehigh Valley Coal Co. at West Superior, Wis., to store coal from lake vessels, is practically a 50,000-ton trimmer-truss inclosed in a circular dome-shaped building, Fig. 13. The roof is supported by steel-dome construction and the low vertical sides by retaining bands buried in the coal. Storing is accomplished by the use of the usual trimmer-conveyor with movable bottom, the only drop being for the first coal deposited until this makes

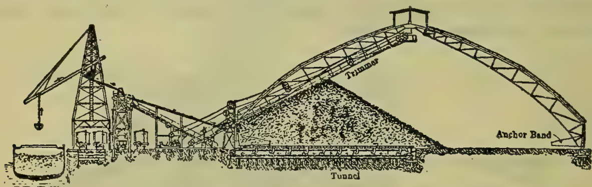


Fig. 13. Covered storage plant.

a pile reaching to the point of trimmer entrance into the building. Reloading is accomplished by the use of a tunnel-conveyor extending to the center of the building, into which the coal tributary by gravity is admitted by valves in the roof of the tunnel. When all the coal thus available has been removed, a reloader, pivoted at the center of the building, has been uncovered and this delivers the balance of the contents to the tunnel conveyor. All the coal is elevated by this to a loading tower, where rescreening can be properly accomplished.

The cost of this plant, which comprises two such buildings, was about $3 per ton of capacity. Except for the breakage in unloading vessels the stocking breakage should but little exceed that of a standard Dodge plant, while the reloading breakage would be somewhat greater by reason of the drop into the tunnel conveyor, the necessity of drawing the first of the coal under pressure, and the double handling by reloader and tunnel of part of the coal.

The plant, being all of metal, is practically fireproof, the main disadvantage being the lack of flexibility. Only one size of coal can of course be stored in each building, and any size stored must be entirely reloaded before the building is available for a different size.

A covered plant of 100,000 tons' capacity, built at Wende, near Buffalo, by the Lehigh Valley Coal Co., in 1906, Fig. 14, has also some unique features. The building is 480 ft. long by 250 ft.

wide. The front and rear walls, 20 ft. high, are braced by a retaining band, and the end walls and two partitions are secured by tie-rods from double lines of piles. The curved roof is supported by steel trusses, the lower members of which are on the angle of repose of piled coal.

Each of the three pockets is provided with a central trimmer conveyor for stocking, and a central tunnel conveyor with valves on 14-ft. centers for reloading. The tunnel conveyors carry the coal each to its own reloading tower provided with proper screening facilities, and the coal which is not tributary by gravity to the tunnels is brought to them by dock-scrapers.

The driving is done by rope from a centrally-located engine.

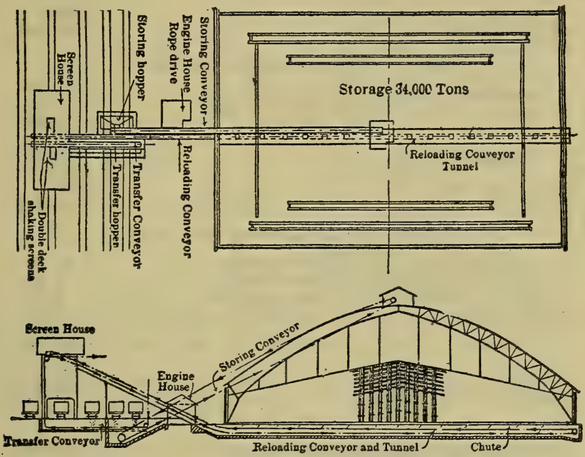


Fig. 14. Wende storage plant, Lehigh Valley Coal Co., Buffalo, N. Y. Plan and cross section.

The cost of the plant approximated $2.25 per ton of capacity, and the operating expense is said to be moderate. Breakage should approximate that of the plant previously described, over which this plant appears to have the advantages of lower first cost, greater handling capacity, less area occupied, and provision for three sizes of coal.

In general, it appears that mechanical storage has distinct advantages over non-mechanical, and the Dodge type with its modifications is best suited to extensive storage plants, and the traveling tramway to smaller plants and to secondary wholesalers' installations. All the non-mechanical plants involve such serious breakage in stocking as to warrant the greater first cost of the mechanical types.

Labor Costs of Handling Coal and Ashes at Locomotive Coaling Stations. According to H. J. Edsall, who gives Tables XI and XII in Engineering News, Sept. 8, 1910, labor costs from 2 cts.

TABLE XI. LABOR COSTS FOR HANDLING COAL AT LOCOMOTIVE COALING STATIONS

Station No. 1. Av. No. locomotives per day, 120

Men employed	Cost per day
1 foreman, $55 per month	$1.80
5 men to unload cars 10 hrs. per day	7.00
2 coal dumpers, 12 hrs. per day	2.80
Total	$11.60
Tons per day	550
Cost per ton	$0.021

No. 2. 120 locomotives per day.

1 machinery man 10 hrs. per day	$1.50
5 men to unload cars 12 hrs. per day	6.50
2 coal dumpers, 12 hrs. per day	2.60
Total	$10.60
Tons per day	550
Cost per ton	$0.019

No. 3. 76 locomotives per day.

½ foreman's time at $66 per month	$1.10
1 machinery man at $55 per month	1.80
3 men to unload cars 10 hrs. per day	4.50
2 coal dumpers, 11 hrs. per day	3.30
Total	$10.70
Tons per day	500
Cost per ton	$0.021

No. 4 *

½ foreman's time at $66 per month	$1.10
1 engineer at $55 per month	1.80
½ fireman's time, 11 hrs. per day	0.83
2 machinery men, 11 hrs. per day	3.30
3 men to unload cars	4.95
2 coal dumpers	3.30
Total	$15.28
Tons per day	625
Cost per ton	$0.024

* Wages estimated from those paid at previous stations.

TABLE XII. LABOR COSTS FOR HANDLING ASHES AT LOCOMOTIVE COALING STATIONS

No. 1:*	Men employed	Cost per day
Amt. ashes assumed at 40 cu. ft. per loco. Wages assumed. Av. No. locomotives per day, 60.	5 day and 5 night men to operate mach'y, feed ashes to same and clean fire boxes	$15.00

No. 2:† Assumed that three 25-ton coal cars = 120 cu. yds. Locomotives per day, 75.	½ of foreman's time at $66 per month	1.10
	1 day and 1 night man to operate gates of ash hoppers	3.30
		$4.40
	6 day and 6 night fire box cleaners, 11 hrs. per day	$19.80
		$24.20
No. 3:† Assumed that six 25-ton coal cars = 240 cu. yds.	Average cu. yds. per day	120
	Cost pits to pockets per cu. yd.	$0.037
	Cost per cu. yd. including cleaning fire boxes	$0.202
	½ of foreman's time at $66 per month.......	$1.10
	1 day and 1 night machinery man	3.30
	1 day and 1 night man to operate gates of hoppers	3.30
		$7.70
	10 day and 10 night fire box cleaners	33.00
		$40.70
	Average cu. yds. per day	240
	Cost pits to pockets, per cu. yd.	$0.032
	Cost per cu. yd. including cleaning fire boxes	$0.169

* At Station No. 1, ashes are deposited in pits about 50 ft. long and scraped to either of two conveyors. Machinery operated 1½ to 3 hrs. per day, usually only morning and evening. Average cu. yds. per day 88.

† At Stations No. 2 and No. 3, ashes are deposited in hopper and fed directly to conveyors, which have to be operated each time the hoppers become filled up.

to 2½ cts. per ton for coal, and from 1⅔ cts. to 2 cts. per cu. yd. for ashes.

Cost of operation and maintenance of gravity-discharge elevators handling coal at locomotive coaling stations:

Station.	No. tons handled	Operation, cost per ton	Maintenance, cost per ton	Operation and maint., cost per ton
No. 1.	16,704 tons per mo. (av. of 12 mos.)	$0.0206	$0.0080	$0.0286
No. 2.	27.313 tons in one year, ending Sept. 30, 1908........	....	.0005	....
No. 3.	37.102 tons, 1906	.0367	.0048	.0415
	46,283 tons, 1907	.0319	.0010	.0329
	49,325 tons, 1908	.0367	.00006	.03676
No. 4.	12.711 tons, 1906	.0299	.0002	.0301
	13,934 tons, 1907	.0323	.0017	.0340
	11,542 tons, 1908	.0352	.0009	.0361
No. 5.	10.910 tons, 1906	.0260	.0000	.0260
	13.970 tons, 1907	.0241	.0003	.0244
	9,416 tons, 1908	.0246	.0005	.0251

Estimated operating costs for a large locomotive coaling station for handling 750 tons of coal per day by means of two gravity discharge elevator conveyors are as follows:

	Cost per day
½ of foreman's time, at $66 per mo.	$1.10
4 men to unload cars, 15c. per hr. 10 hrs. per day	6.00
1 day and 1 night coal dumper (to tenders) 15 cts. per hr., 11 hrs. per day	3.30
	$10.40
Cost per ton, cts.	$0.015
Items pertaining directly to this system:	
1 man to run coal conveyors, $55 per month each	1.80
15 h.p. for 10 hrs. at 2 cts. per h.p.-hr	3.00
Supplies	.50
	$15.70
Cost per ton, cts.	$0.025

For handling 250 cu. yds. of ashes per day by means of two pivoted bucket carriers the costs are as follows:

	Cost per day
½ of foreman's time at $66 per mo.	$1.10
6 men to scrape and feed ashes to conveyors, 15 cts. per hr., 10 hrs. per day	9.00
	$10.10
Cost per ton, cts.	$0.04
Items pertaining directly to this system:	
1 day and 1 night man to run ashes to conveyors, $55 per month each	$3.60
Cost of 2 h.p. for 10 hrs. at 2 cts. per h.p.-hr.	.40
Cost of supplies	.60
	$14.70
Cost per ton, cts.	$0.059

TABLE XIII. OPERATING AND MAINTENANCE COSTS OF SEVERAL LOCOMOTIVE COALING STATIONS FOR ONE YEAR

Type	Tons handled	Repairs, labor and material per ton	Switching charges per ton	Labor dumping and coaling per ton	Fuel for operating machinery, per ton	Total expense, per ton
Bucket elevator	130,850	0.21	0.71	3.36	0.63	4.91
Inclined belt conveyor	62,899	2.36	0.70	5.81	0.79	9.66
Bucket elevator	43,321	0.74	1.05	2.30	0.87	4.96
Bucket elevator	183,410	1.32	0.69	2.47	0.30	4.78
Inclined belt conveyor	47,109	3.09	0.71	5.25	0.67	9.72
* Trestle	110,138	†	0.74	4.21	...	4.95
* Trestle	276,397	†	0.74	3.05	...	3.79
* Trestle	61,570	†	1.30	3.34	...	4.64

* Locomotive places cars.
† No record kept of repairs.

TABLE XIV. OPERATING COSTS OF AN 80 FT. RADIUS CRANE.—COAL STORAGE AND LOCOMOTIVE COALING SERVICE

	December, 1907	January, 1908.	February, 1908.
Tons coal in storage first day of month	38,717	35,578	18,741
Tons stored during month	725	000	000
Tons delivered to engines	9,624*	9,718	8,615
Tons reloaded for shipment	000	7,119	7,406
Total tonnage handled in month	10,349	16,837	16,021
Number hours crane operation	210	285	276
Tons handled per hour operation	49.28	59.08	58.23
Repairs to crane:			
Labor	$6.28	$17.54	....
Material	1.76	1.50	....
	$8.04	$19.04	0.00
Crane operating charges:			
Labor	$100.25	$102.16	$88.75
Fuel	44.25	75.00	60.00
Supplies	5.64	7.49	4.28
	$150.14	$184.65	$155.03
Labor unloading cars into track pit	$80.10	0.00	0.00
Labor coaling locomotives from storage bin	$84.18	$80.15	†0.00
Labor clearing coal from track before machine	0.00	0.00	$69.12
Coal pocket repairs	0.00	$124.43	$5.59
Switching services:			
Labor	$76.26	$120.28	$40.51
Fuel	45.00	77.50	32.50
Supplies	8.24	6.03	4.22
	$129.50	$203.81	$77.23
Total operation cost for month	$451.96	$612.08	$378.95
Total cost per ton putting coal into storage	$.0529	.....	.....
Total cost per ton delivering coal to engines	$.0429	$.0278	$.0228
Total cost per ton reloading coal for shipment	.....	$.0487	$.0248
Total cost per ton coal handled by crane	$\frac{451.96}{10,349}$ = $.0437	$\frac{612.08}{16,837}$ = $.0363	$\frac{378.95}{16,021}$ = $.0236

* Of this amount 2,864 tons were taken from storage and 6,760 tons were loaded directly from cars to locomotive tenders.

† All coaling was by crane from storage piles direct to tenders.

We are indebted to Wilbur D. Hudson for the above notes.

TABLE XV. OPERATING COSTS OF LOCOMOTIVE COALING PLANTS

(From data collected by the Committee on Buildings, American Railway Engineering and Maintenance of Way Association).

	Trestles with elevated bins; small dump cars unloaded by shoveling. Williams-White type.			High trestles with self-clearing cars delivering directly into storage bins.			High trestles with power-operated incline.				Locomotive Crane.	Mechanical plant with elevating and conveying machinery.			Mechanical plant with inclined belt conveyor.		
Months covered by data	9	...	†	10	1	1	9	3	1	1	24	6	1	..	10	12	3
No. of stations averaged	4	5	1	6	2	17	1	1	5	55	3	1	3	4	4	1	1
Tons handled per day	235	133	13	305	370	440	67	264	166	82	195	165	147	345	280	127	218
Int. and depreciation cts. ..	0.8	*1.0	1.7	0.5	*1.2	*0.8	2.3	1.7	2.7	2.7	1.5	*3.7	2.5	1.8	1.7	3.2	3.3
Operation, cts. ..	10.3	11.3	20.6	3.1	6.1	3.6	2.8	3.5	5.1	7.0	3.9	2.7	3.7	2.4	2.7	4.3	3.1
Maintenance, cts.	0.5	*0.5	2.2	0.5	*0.6	*0.4	0.1	*0.8	*1.3	0.9	0.5	*1.0	*1.0	0.5	0.5	0.6	0.5
Total operating costs per ton	11.6	12.8	24.5	4.1	7.9	4.8	5.2	6.0	9.1	10.6	5.9	7.4	7.2	4.7	4.9	8.1	6.9

* Estimated.
† Buckets and jib crane.
For interest and depreciation 10% of the original cost of the plant was used regardless of the type.

Annual Operating and Maintenance Cost of Several Locomotive Coaling Stations. The following notes are from Engineering News April 16, 1908:

Data on one month's operation of a Pittsburg locomotive coaling plant are as follows:

Number of engines supplied..........	766	
Maximum time per engine...........	5	minutes
Minimum time	2	"
Average time	2.86	"
* Total cost	$92.00	
Cost per engine	12 cts.	
Average tons per engine	4½	
Cost of coaling per ton	2.67 cts.	
Number of tons hoisted during month.	3,606	
Average time per carload	1 hr. 37 mins.	
Total cost for hoisting	$49.50	
Cost per ton	1.37 cts.	
* Cost of hoisting and coaling.........	4.04 cts.	

* Including labor, repairs, power, and fuel, but not interest on the investment.

Operating Costs. In Table XV the cost of operating conveyor plants varied from 4 to 8.1 cts. (total cost of handling coal per ton). These costs will usually be lower as the tonnage handled is greater. The following figures are supplementary to Table XV. The average labor costs from 12 stations of railway in the Middle West is 1.4 cts. per ton. A typical record of one pocket near Pittsburg for one month is shown.

Detailed records of the cost of operating 8 coaling stations and trestles along the lines of large eastern railroads were kept carefully and give an interesting record. Table XIII shows the type of plant, the number of tons handled during the year, repair and operating costs and switching charges.

This is an interesting table and worthy of considerable study. The two-belt conveyor installations noted were at a disadvantage in handling material at nowhere near the full capacity of the belts, and in each case a new belt was charged up against the station during the year covered by the data. Wear on conveying belts is due principally to the bending of the belt back and forth and the cost of repairs per ton handled by a belt conveyor will be considerably lower where it can be operated at maximum loads. The figures for trestles are misleading, because no labor or material for repairs were charged against them for the year covered by the record. These charges are small for the first 10 or 12 years of operation and considerable thereafter. The mechanically operated stations are unquestionably the most economical in the long run.

Comparative Cost of Handling Fuel in a Boiler House by Hand and by Telpher. Henry J. Edsall published in Power in 1912 the following comparative analysis:

A comparison of two boiler houses with the same boiler and stoker equipment, and the coal handled mechanically in one case and by hand in the other follows.

Boiler House A. A cross-section of boiler house A is shown in Fig. 15. The boilers are set in two rows, with a low trestle between, on which the coal cars are run in and unloaded, so that the coal is placed directly within reach of the firemen; no wheeling or second handling is necessary before shoveling it into the stoker hoppers, unless the coal pile under the trestle gets low.

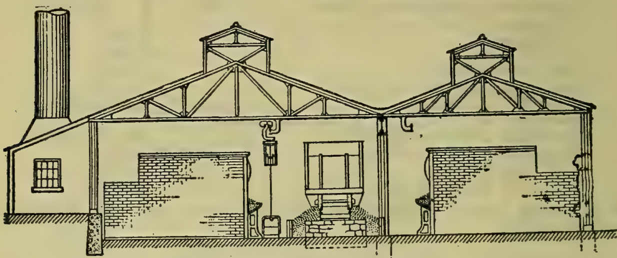


Fig. 15. Boiler house without conveyor system, ashes removed by means of a telpher.

In addition to shoveling the coal, there is the additional labor of breaking up the large lumps and, as this is not always properly done, there is more or less grate-bar trouble with the stokers, thus reducing the efficiency of the steam plant as well as the additional cost of maintenance on the stokers.

Ash Handling. For ash-handling there is a bucket carried by an electrically operated telpher running on an overhead track. The ashes are raked from under the stokers up to the boiler-room floor and then shoveled into the bucket, which takes them out and delivers them into a railroad car. This means considerable labor and, as there is but little room between the boilers and the coal pile, the men get into each other's way.

Boilers. There are sixteen 260-h.p. Babcock & Wilcox boilers in this boiler house, and all are equipped with Roney stokers. This makes a total rated capacity of 4160 h.p. At the time the figures were obtained only 10 boilers were in use, the other 6 being cleaned and repaired.

The weekly coal consumption with 10 boilers in service averages about 910 tons, or 91 tons per boiler. Assuming roughly 10% ash, there would be about 91 tons of ashes to be disposed of each week. Table XVI gives the total weekly cost for labor, power and supplies directly connected with coal- and ash-handling.

In Table XVII the figures for boiler house A are changed to what they would be with 12 boilers in service, thus affording a direct comparison with boiler house B, where there are, as a rule, 12 boilers in use. The only changes are providing a fireman for each additional boiler, both day and night, and a slight increase in the power cost.

Boiler House B. In boiler house B there are fourteen 260-h.p.

TABLE XVI. BOILER HOUSE A COSTS. COAL TRESTLE AND ASH TELPHER EQUIPMENT

(Sixteen 260-hp. boilers, ten in service; weekly coal consumption, 910 long tons).

No. of men	Preformance of men	Total per week
1	Telpher operator (day) 79 hrs. at 0.18	$14.22
1	Telpher operator (night) 89 hrs. at 0.18	16.02
3	Loading ashes to telpher (day) 79 hrs. at 0.18	42.66
3	Loading ashes to telpher (night) 89 hrs. at 0.18	48.06
3	Unloading coal from cars (day) 72 hrs. at 0.15	32.40
2	Unloading coal from cars (night) 78 hrs. at 0.14	21.84
1	Chief (day) 79 hrs. at 0.25	19.75
1	Chief (night) 89 hrs. at 0.25	22.25
1	Assistant chief (day) 79 hrs. at 0.22½	17.78
1	Assistant chief (night) 89 hrs. at 0.22½	20.03
10	Fireman (day) 79 hrs. at 0.18	142.20
10	Fireman (night) 89 hrs. at 0.18	160.20
		$557.41
	150 hp.-hr. for telpher motor at 3 cts.	4.50
	Supplies for telpher	2.00
	Total per week	$563.91

Babcock & Wilcox boilers, or a total of 3640 h.p. Usually 12 of these boilers are in use at one time, the other two being held for cleaning and repairs. In this boiler room the coal is fed from an overhead bin to the Roney stokers and a conveyor system handles both the coal and the ashes. The run-of-mine soft coal is unloaded into a track hopper underneath the track, then delivered to the crusher by means of an apron feeder, and after passing through the crusher a bucket carrier elevates it and distributes it in the overhead bin. The ashes are raked out of

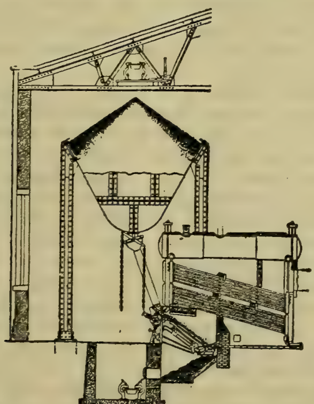


Fig. 16. Section through boiler house showing conveyor system.

the hoppers and into the lower run of the carrier, which elevates them to an ash pocket from which they are discharged into railroad cars. Fig. 16 shows a cross-section of the boiler room thus equipped.

Coal Consumption. The average amount of coal consumed per week with 12 boilers in service is about 1260 tons, or 105 tons per boiler. This is an increase of about 15% over the amount of coal consumed by the boilers in boiler house A, which means that a greater output of steam is obtained from these boilers, because the coal is properly crushed and is fed continuously to the stokers, resulting in better and more even fires. Figuring 10% ash, as before, about 126 tons of ashes are disposed of.

Hours and Wages. The hours and wages of the men are given in Table XVII, which shows a total weekly labor cost of $395. The power used for handling coal is figured on the basis of 30 tons per hr., which is about the average amount handled. This gives a total of 42 hrs. per week, and taking the average h.p. consumed as 20, gives a total of 840 h.p.-hrs. per week for handling coal. The actual amount of power used in handling ashes is hard to determine, but 660 h.p.-hrs. per week would cover it, making a total of 1500 h.p.-hrs. per week for handling both coal and ashes.

This gives a total weekly cost of $445 for boiler house B against a cost of $625 for boiler house A, or a saving of $180 per week and $9360 per year. This does not include the cost of maintenance and the depreciation of the coal- and ash-handling equipment or the interest on the investment in either case.

Overhead Bin and Conveyor System. Since the foregoing figures were obtained, four more boilers have been installed in boiler house A and, as the possible saving increases with a greater number of boilers, the advantages of an overhead bin and conveyor system for handling both coal and ashes are still more strikingly shown when the costs for this boiler house, with twenty boilers, are worked out.

Such a comparison is shown in Table XVIII, the first part showing the costs with the present type of equipment and the second part showing the costs with the overhead bin and conveyor system, the number of boilers in service being assumed as 16, and the wages, etc., being based on the actual figures obtained for the two boiler houses. No men are added for the present type of equipment except the firemen, though with this number of boilers in service there might be more men required for loading ashes to the telphers or for unloading coal from the cars.

With the overhead bin and conveyor system two day men and two night men are included for handling ashes. Having an efficient modern system this number should be ample; in fact, one man should be able to handle the 10 or 12 tons of ashes on each shift — about one ton per hour.

The excavating and concrete work for the ash hoppers and tunnels, etc., would make the installation of this system in an old boiler house considerably more expensive than in a boiler house

designed especially to suit these conditions. The total cost of installation has, therefore, been assumed as $50,000, including an overhead coal bin with a capacity of 900 tons.

Cost of Maintenance. Assuming then that a loan of $50,000

TABLE XVII. COAL AND ASH HANDLING COSTS

BOILER HOUSE A

With Present Coal Trestle and Ash Telpher Equipment

(Twenty 260-hp. boilers, sixteen in service; weekly coal consumption, 1,466 long tons).

No. of men	Performance of men	Total per week
1	Telepher operator (day) 79 hrs. at 0.18	$14.22
1	Telepher operator (night) 89 hrs. at 0.18	16.02
3	Loading ashes to telpher (day) 79 hrs. at 0.18	42.66
3	Loading ashes to telpher (night) 89 hrs. at 0.18	48.06
3	Unloading coal from cars (day) 72 hrs. at 0.15	32.40
2	Unloading coal from cars (night) 78 hrs. at 0.14	21.84
1	Chief (day) 79 hrs. at 0.25	19.75
1	Chief (night) 89 hrs. at 0.25	22.25
1	Assistant chief (day) 79 hrs. at 0.22½	17.78
1	Assistant chief (night) 89 hrs. at 0.22½	20.03
16	Firemen (day) 79 hrs. at 0.18	227.52
16	Firemen (night) 89 hrs. at 0.18	256.32
		$735.85
	Weekly cost of power for telpher	8.15
	Weekly cost of supplies for telpher	3.00
	Total per week	$750.00

BOILER HOUSE A

Equipped with Overhead Bin and Conveyor System for Handling Coal and Ashes.

(Twenty 260-hp. boilers, sixteen in service; weekly coal consumption, 1,680 long tons).

No. of men	Performance of men	Total per week
1	Conveyor operator (day) 76 hrs. at 0.30	$22.80
1	Conveyor operator (night) 85 hrs. at 0.30	25.50
2	Disposing of ashes (day) 76 hrs. at 0.16½	25.08
2	Disposing of ashes (night) 85 hrs. at 0.16½	28.06
3	Unloading coal from cars (day) 72 hrs. at 0.15	32.40
1	Chief (day) 79 hrs. at 0.25	19.75
1	Chief (night) 89 hrs. at 0.25	22.25
1	Assistant chief (day) 79 hrs. at 0.22½	17.78
1	Assistant chief (night) 89 hrs. at 0.22½	20.03
8	Firemen (day) 79 hrs. at 0.18	113.76
8	Firemen (night) 89 hrs. at 0.18	128.16
		$455.57
	Weekly cost of power for modern conveyor system	40.00
	Weekly cost of supplies for modern conveyor system	4.43
	Total per week	$500.00

is obtained at 5% interest, and that 3% per year will cover the cost of maintenance, the following saving is effected:

Weekly saving, $750 — $500 = $250; yearly saving, $250 × 52 = $13,000.

That is, the installation would pay for itself in a little over 5

years, and each year after this shows a clear saving of several thousand dollars. The 3% for maintenance should be ample, as much of the installation cost is for foundation work, concrete and steel bins, etc., which work would be either permanent or require but little for maintenance. Besides, coal and ash convey-

TABLE XVIII. COST OF COAL AND ASH HANDLING

BOILER HOUSE A

Coal Trestle and Ash Telpher Equipment.

Sixteen 260 h.p. boilers, 12 in service, weekly coal consumption, 1,092 long tons.

No. of men	Performance of men	Total per week
1	Telpher operator (day) 79 hrs. at 0.18.	$14.22
1	Telpher operator (night) 89 hrs. at 0.18	16.02
3	Loading ashes to telpher (day) 79 hrs. at 0.18	14.22
3	Loading ashes to telpher (night) 89 hrs. at 0.18	16.02
3	Unloading coal from cars (day) 72 hrs. at 0.15	10.80
2	Unloading coal from cars (night) 78 hrs. at 0.14	10.92
1	Chief (day) 79 hrs. at 0.25	19.75
1	Chief (night) 89 hrs. at 0.25	22.25
1	Assistant chief (day) 79 hrs. at 0.22½	17.78
1	Assistant chief (night) 89 hrs. at 0.22½	20.03
12	Firemen (day) 79 hrs. at 0.18	14.22
12	Firemen (night) 89 hrs. at 0.18	16.02
		$617.89
	Weekly cost of power for telpher	5.11
	Weekly cost of supplies for telpher	2.00
	Total per week	$625.00

BOILER HOUSE B

Overhead Bin and Conveyor Equipment

Sixteen 260 h.p. boilers, 12 in service; weekly coal consumption, 1,260 long tons.

No. of men	Performance of men	Total per week
1	Conveyor operator (day) 76 hrs. at 0.30.	$22.80
1	Conveyor operator (night) 85 hrs. at 0.30	25.00
2	Feeding ashes to conveyor (day) 76 hrs. at 0.16½	25.08
2	Feeding ashes to conveyor (night) 85 hrs. at 0.16½	28.06
3	Unloading coal from cars (day) 72 hrs. at 0.15	32.40
1	Chief (day) 79 hrs. at 0.25	19.75
1	Chief (night) 89 hrs. at 0.25	22.25
1	Assistant (day) 79 hrs. at 0.22½	17.78
1	Assistant (night) 89 hrs. at 0.22½	20.03
6	Firemen (day) 79 hrs. at 0.18	85.32
6	Firemen (night) 89 hrs. at 0.18	96.12
		$395.09
	Weekly cost of power for conveyor system (1,500 h.p.-hrs. at 3 cts. per hr.)	45.00
	Weekly cost of conveyor system supplies	4.91
	Total per week	$445.00

ors have reached a point of perfection in design and construction where they will stand up wonderfully well under very severe service, and the handling of both coal and ashes in one carrier is now good engineering practice.

In fact, a well designed carrier embodying first-class construc-

tion throughout should, when handling both coal and ashes, require little or no repairs in the first 4 or 5 years, and after this 3% per year would probably cover them, unless the amount handled is unusually large, in which case the cost per ton of material would show to even better advantage.

Cost of Economic Features of Modern Locomotive Coaling Stations. A committee of the International Railway Fuel Association made a report at an annual convention of that organization on the design, construction, operation and maintenance of modern locomotive coaling stations, which was abstracted in Engineering and Contracting, 1913.

The report is based on a set of questions which it prepared and the answers to the questions as received from members of the association. The committee recognize the following seven types of locomotive coaling stations:

(1) Gravity chute, self-clearing cars, handled up incline by locomotives or gasoline or electric hoist. (2) Balanced buckets, using gasoline, steam or electric power, self-clearing cars, coal dumped into pit and elevated by one to four balanced buckets, holding one to three tons each. (3) Bucket conveyor, type using gasoline, steam or electric power, self-clearing cars, coal dumped into pit and hoisted to main bin by small buckets on chain or link-belt. (4) Inclined conveyor, rubber or canvas belt; gasoline, steam or electric power, self-clearing cars, coal dumped into pit and conveyed to main hopper on the inclined belt. (5) Locomotive crane and clam-shell, gondola flat-bottom cars used, coal handled direct from cars to locomotive tenders. (6) Hydraulic power-hoist loaded railroad cars and dump into main hopper by inverting the cars. (7) Inclined trestle with pockets, shovel coal from cars to pockets, served by locomotive.

Having in mind the cost of installation, operation, maintenance and depreciation the following recommendations were made by certain members as to the foregoing general types:

Type 1 is generally favored where there is sufficient room for the construction of the incline approach. but naturally the cost of property in the larger terminals would materially offset any advantage that might be claimed. Eight members favor this type for large stations, handling 10,000 tons or more per month, and where not more than two tracks are to be served. One member recommends that road cars be handled by locomotives. One member calls particular attention to the advisability of raising the cars high enough that the road cars may be dumped direct into the serving pockets, saving expense of shoveling and breaking of coal. It must not be forgotten that the railroads still retain a large percentage of flat-bottom non-dumping gondolas, from which the coal will continue to be shoveled. Storage of coal with Type 1, except such as may be provided through the medium of the pockets and the road cars, is practically prohibitory, due to the additional initial cost.

Type 2 is recommended by twelve members for locations where the space is restricted and where two or more tracks are to be

served. This type is particularly favored for large stations serving 50 or more locomotives, and, in fact, for any service calling for an issue of 100 or more tons of coal daily. As this type calls for the installation of considerably machinery, due care should be given its permanent location where it will not be disturbed by future improvements.

Type 3 has been endorsed by 3 members for use at the larger stations where 2 or more tracks are to be used. It is particularly recommended that wherever Types 2 or 3 are used that the plant be provided with a duplicate hoisting arrangement.

Type 4 has not been mentioned in any of the replies received.

Type 5 — Seven members have recommended the locomotive crane and clam-shell for the smaller stations, and for temporary use where the larger plant cannot be permanently located. This type is favored as being very flexible in its use in any class of road cars, and its adaptability to many purposes at any point on the railroad.

Type 6 — No mention was made.

Type 7 — for smaller stations handling less than 50 tons per day, where the physical conditions would prohibit the use of the more expensive plant, this type has been recommended by three of the members.

Frame construction is favored for small plants and where they are isolated from other buildings and where first cost is an important element. One reply recommends the use of concrete foundations, and another recommends the use of creosoted timbers. Wherever frame is used, ample precautions, such as stand-pipes with hose connections, hand-grenades and fire extinguishers, should be generously provided, and it is thought that possibly the additional expense for fire protection may, at times, more than offset the increased cost of steel or concrete construction.

Steel is recommended in preference to frame or concrete where fireproof construction is desirable, and where there is any possibility that the tracks may be altered at some future time, requiring the moving of the plant. All steel that comes in contact with the coal should be protected by concrete.

Concrete is favored where the cost is not prohibitory for use in all mechanical plants that are permanently located.

A combination of frame, steel and reinforced concrete would appear to be economical and safe for Type 1. Trestle approach to be of creosoted timbers on concrete piers. Framing of supports

TABLE XIX. COST OF OPERATION

Type.	1.	2.	4.	7.
Average tons handled in 24 hrs. summer	130	120	320	110
Average tons handled in 24 hrs. winter.	170	180	390	145
Average tons used in 24 hrs. summer.	130	120	320	110
Average tons used in 24 hrs. winter.	170	180	390	145
Cost of labor per ton, cts.	3.4	2.5	3.5	7.79
Cost of power per ton, cts.	0.19	0.28	0.38	...
Cost of supplies per ton, cts.	0.01	0.02	0.02	0.01
Total per ton, cts.	3.6	2.8	3.9	7.8

under bins, hoppers and general structure to be of steel. Bins and any other parts coming in contact with the coal to be reinforced concrete slabs. The same general method of construction could be used for the other types, omitting the frame approaches.

As a general rule the storage of surplus coal is not recommended, except to overcome temporarily local or general failures of transportation, or mining, or on account of possible car shortage. The general objection being the deterioration of the heat values. One member recommends storing two weeks' supply in winter months and another suggests that there might be conditions where it would not be objectionable to store thirty days' supply. Another member recommends keeping a storage supply with the necessary facilities to unload, store and reload on every Division.

One reply received is so strongly in favor of storing a supply that it is quoted as follows:

Coal should be stored in summer for winter use for the following reasons: (a) To have the equipment which would otherwise be in use in company coal service available for revenue coal service. (b) As the cost of haulage of company coal, as well as all freight, is higher in cold weather than in warm, it is economical to haul as much as possible in warm weather. (c) To give the mine operators every opportunity to sell all commercial coal possible at the period when the highest prices are obtainable. (d) To increase the operator's summer orders with the result that they can hold their miners through the summer, and be ready to put out a large winter tonnage. (e) For economy of purchase, as summer storage coal could usually be purchased at a lower price than coal purchased under a contract with a maximum twice the minimum, and orders even running below the minimum in summer.

It is the general opinion that it is good practice to unload storage coal, particularly to relieve cars earning per diem or losing revenue. All parties agree that when coal is stored on the ground, it should be piled on plank-car-siding-ties or other similar material.

COST DATA

Believing that the question of cost is the most important consideration in determining the proper type of a modern locomotive coaling plant the committee presented in full all the cost data received from members who gave the type of chute used in connection with the costs. Six replies of this character were received and are here quoted:

A — *Two balanced buckets, 350 tons capacity.*
First cost, $22,000.
Cost of operation, 2 to 8 cts. per ton; average cost 3½ cts. per ton.
Cost of maintenance, 2 cts. per ton.
Fixed charges, interest 5% and depreciation 5% per annum, 2 cts. per ton.
Link belt, bucket conveyor, 700 tons capacity.
First cost, $37,000.

Cost of operation, 1.7 cts. per ton.
Cost of maintenance, 1.4 cts. per ton.
Fixed charges, interest 5% and depreciation per annum 5%, 1.5 cts. per ton.

Link belt, bucket conveyor, 150 tons capacity.
First cost, $9,000.
Cost of operation, 5.6 cts. per ton.
Cost of maintenance, 3.0 cts. per ton.
Fixed charges, interest 5% and depreciation 5% per annum, from 1 ct. to 2 cts. per ton.

Inclined conveyor, belt, 150 and 350 tons capacity.
First cost, $10,400 and from $13,000 to $23,000.
Cost of operation, from 1.5 cts. to 8.8 cts. per ton.
Cost of maintenance, from 0.1 ct. to 0.7 ct. per ton.
Fixed charges, interest 5% and depreciation 5% per annum, from 1.4 cts. to 3.6 cts. per ton.

Locomotive crane.
Average total cost, 20 cts. per ton.

Inclined trestles with pockets.
First cost, $4,000 to $12,000.
Cost of operation, from 1 ct. to 5 cts. per ton.
Cost of maintenance, average 2 cts. per ton.
Fixed charges, interest, 5% and depreciation 10% per annum, from 1 ct. to 2 cts. per ton.

Large balanced buckets, 15 tons capacity, running up vertically and over horizontal track, capacity, 1,500 tons.
First cost. $64,000.
Cost of operation, 2 cts. per ton.
Cost of maintenance, 3 cts. per ton.
Cost of maintenance, 3 cts. per ton.
Fixed charges, interest 5% and depreciation 10% per annum, 1.6 cts. per ton.

B.— Bucket conveyor.

Average tons handled and used July	257 tons
Average tons handled and used December	542 tons
Cost of labor, July	2.3 cts. per ton
Cost of labor, December	2.4 cts. per ton
Cost of power, July	1.0 cts. per ton
Cost of power, December	0.9 cts. per ton
Cost of supplies, July	0.59 cts. per ton
Cost of supplies December	0.6 cts. per ton
Total cost, July	3.89 cts. per ton
Total cost, December	3.90 cts. per ton

Locomotive crane and clam shell.

Average tons handled and used, July	247 tons
Average tons handled and used, December	356 tons
Cost of labor, July	4.4 cts. per ton
Cost of labor, December	3.0 cts. per ton
Cost of power, July	0.19 cts. per ton
Cost of power, December	0.15 cts. per ton
Cost of supplies, July	0.25 cts. per ton
Cost of supplies, December	0.28 cts. per ton
Total cost July	4.84 cts. per ton
Total cost December	3.43 cts per ton

C — The data given in reply C are shown in Table XIX.
D — Figures submitted in Table XX, reply D, are for the month of November, 1912.
E — Type, 300 to 500 tons' capacity.
Hoists by means of cable running side dump cars up incline at the rate of 45 tons every 15 minutes.
Total cost on locomotive — 1.5 cts. to 2 cts. per ton.
F — Inclined gravity chute type.
Capacity — Summer, 520 tons; winter, 730 tons.
Cost, not including power for elevation by locomotives nor for supplies — Summer, 1 ct. per ton; winter, 0.9 ct. per ton.

TABLE XX. COST OF OPERATION

	Balanced bucket stations					Inclined belt stations				Chain and bucket station
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Fixed charges (5% interest, 5% depreciation)	.0083	.0036	.0044	.0146	.0103	.0111	.0181	.0384	.011	.0053
Operating expenses (power and labor)	.0192	.0096	.0243	.0195	.0165	.0267	.0305	.0311	.02	.0128
Maintenance	.0005	.0058	.0017	.0329	.0083	.0096	.0105	.0035	.009	.005
Pro rata (general office expense)	.0028	.0002	.0004	.0021	.0011	.0008	....	.0038	.001	.0038
Total cost per ton	.0308	.0192	.03089	.0691	.03635	.0482	.0589	.0768	.041	.0236
Tons handled for month	10,375	23,530	16,509	5,165	9,918	17,151	10,888	7,350	12,455	35,727

Balanced bucket type.

Capacity — Summer, 558 tons; winter, 652 tons.

Cost, not including power nor supplies — Summer, 2.6 cts. per ton; winter, 1.9 cts. per ton.

Cost of Handling Coal and Ashes by Locomotive Cranes at Eight Plants. In a paper before the Canadian Society of Civil Engineers in 1908 C. F. Whitton presented a compilation of data regarding the cost of handling locomotive coal and ashes, as developed in the use of various appliances.

The fixed charges, which comprise interest, depreciation, insurance, and taxes, have been taken as 10% of the total initial cost of the plant. Maintenance and operating charges vary so widely with local and climatic conditions, that, considering also the short time over which the costs obtained extend, they can hardly be considered exact, and certainly not applicable, except as an indication of general results. Pro rata charges are estimated as follows: The proportion of the time of yardmaster, clerks, etc., is distributed to the different departments on a labor output basis, and the per cent. added to the cost of handling coal and ashes is the proportion of the above wages based on the ratio which the labor charges for each of these departments bears to the total labor charges of all the departments of the yard. By several railroads, this amounts to about 20% of the labor charge for the coal and ash handling plants.

The cost of coal handling with a locomotive crane was based upon that obtained at the Cleveland yards of the Erie Railroad, and is as follows:

a.	Average number of locomotives fueled per day..	25
b.	Average tonnage per 12 hrs.	168
c.	Maximum actual tonnage per 12 hrs.	180
d.	Total tonnage for year 1906	60,500

The initial cost of the crane was $7,400, and the cost of bucket, pits, etc., is estimated at $4,600. The handling costs per ton are made up as follows:

Average tons handled per day	166	
Fixed charges, per ton	2	cents
Operating charges, labor	2	"
Operating charges, power and supplies	3.5	"
Maintenance charges	0.3	"
Pro rata charges	0.4	"
Total cost per ton	8.2	"

Other locomotive crane plants show the following costs (p. 371):

The cost of handling ashes does not include any proportion of the fixed charges.

The actual cost per ton is not so important as a comparison of costs between old and new methods of doing the work. In the case of the Erie plant, at Cleveland, the reduction per ton due to the installation of a locomotive crane was about 12 cts. At this plant there is another crane not in service at present.

COAL HANDLING

Location	Buffalo	Leipsic	Bellevue.	Ft. Wayne	Conneaut	Stoney I'd.	Cleveland	Mina.	
Year	1905	1905	1905	1905	1905	1905	1906	1906	
Average tons per day	176	116	230	153	106	45	166	218	
Fixed charges	1.9	1.7	1.8	1.8	3.7	7.9	2.0	1.5	cts.
Operating charges	4.7	6.1	3.6	5.1	3.0	5.5	5.5	3.5	"
Maintenance charges	0.5	0.2	0.7	0.5	0.4	0.2	0.3	0.1	"
Pro rata charges	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	"
Total charge per ton	7.5	8.4	6.5	7.8	7.5	14.0	8.2	5.5	"
ASH* HANDLING									
No. of locomotives cleaned per day	20	13	26	17	12	5	19	25	
Cost per locomotive cleaned	4.8	..	3.8	22.4	3.3	4.7	..	..	cts.

The belt conveyor, as operated in the Cleveland yards of the Pennsylvania Lines West, gave the following results:

Average number of locomotives fueled per day	50 to 75
Average tons handled per day (1906)	260
Maximum tons handled per day on a monthly basis	570

The original cost of this plant was $13,000, and it is in operation for 10 hours per day.

The labor connected with this plant includes one engineer in charge of the machinery, and two laborers.

The handling costs for 1906 are made up as follows:

Average tons handled per day	258	
Fixed charges	1.4	cts.
Operating charges	2.8	"
Maintenance charges (belt renewal)	0.2	"
Pro rata charges	0.2	"
Total cost per ton	4.6	"

In these same yards the ashes are handled by an overhead trolley. The first cost of the pits and the mechanism was about $5,000. During 1906, the number of locomotives handled was upward of 18,000, and the cost per locomotive was as follows:

Fixed charges	2.4	cts.
Labor of operating plant	27.5	"
Cost of power and supplies	1.1	"
Maintenance	0.2	"
Pro rata charges	5.6	"
Total cost per locomotive cleaned	36.8	"

For the bucket conveyor the plant of the Lake Shore & Michigan Southern at Elyria, Ohio, served as an example. The capacity of the wharf is about 500 tons, and there are four 125-ton pockets.

Power is supplied to one conveyor by a 32-h.p. gasolene engine making 200 revolutions per minute. For the other system power is derived from a 60-h.p. gasolene engine making 160 revolutions per minute.

Rope transmission is used throughout.

The plant is operated by an engineer, a fireman, and two laborers.

The following figures represent the operation of this plant:

a.	Average No. of locomotives fueled per day	60 to 70
b.	Average daily tonnage — summer	300
c.	Total tonnage for year 1906	88,250

This plant, as originally installed, consisted of the main structure and one conveyor system, and cost $34,000. Later the second conveyor was installed at an estimated cost of about $15,000, but as one conveyor only is in continuous operation at present, the fixed charges have been estimated for the original cost of $34,000.

Average No. of tons handled per day	242	
Fixed charges	3.9	cts.
Operation charges	2.8	"
Maintenance charges	2.1	"
Pro rata charges	0.4	"
Total cost per ton	9.3	"

The figures obtained from the trestle plant of the Lake Shore & Michigan Southern at Collinwood, Ohio, show that it handles from 550 tons per day in summer to 900 tons per day in winter, and that the delivery ranges from 5 to 15 tons per engine, with an average of 10.

The labor force consists of three laborers and a foreman, who also has charge of the ash-pit gang.

The original cost is estimated at $15,000, and the handling costs for 1906 were as follows:

Tons per day	635	
Fixed charges	6.7	cts.
Operating charges	4.1	"
Maintenance charges	0.1	"
Pro rata charges	0.4	"
Total cost per ton	5.3	"

In the case of the ashpits at the same locality, their capacity is as follows:

Average number of locomotives having fires cleaned per day	58
Total number of locomotives having fires cleaned per year.	21,000

The cost of handling ashes is estimated as follows:

Fixed charge	4.8	cts.
Labor	26.1	"
Power, supplies, etc.	1.2	"
Pro rata charge	4.8	"
Total cost per locomotive cleaned	35.7	"

The locomotive crane has offered a very successful and moderately cheap method of handling coal and ashes in locations where the demands are not excessive. Its practical limit is said to be about 70 locomotives a day, as the capacity of the bucket is necessarily below 5 tons, and the number of trips per hour is restricted to about 50.

It is not as rapid as plants having gravity discharge from storage, but, as the engine is necessarily held over the ashpit for about 40 minutes, this feature is hardly objectionable, as delays to engines can be obviated by providing pockets.

The system proves a very flexible one on account of the diversity of arrangements possible. One disadvantage of open-air storage in pockets or pits, however, is the liability of the coal and gates to be frozen up in cold weather. With the necessary tracks, pits, and pockets, it will be found that this sort of plant has a considerable first cost. Its operating cost depends upon the work which can be provided at spare times. Its value is great in emergency situations, and at points where, because of impending changes, the construction of a permanent plant is unwise. With a large terminal where a conveyor plant is used, a locomotive crane can be very valuable to handle cinders and sand, and also coal during a possible breakdown of the conveyor. Then again not only can it unload direct from flat-bottom cars, handle ashes as well as coal, move to any spot desirable to stop the locomotive, but if superseded by a different system, can be easily moved to another point. These are a few of the points of interest concerning the locomotive crane, but within its proper sphere of capacity, it seems to prove one of the very best now in use.

Cost of Handling Coal by the Mechanical Plant of the Wabash R. R. at Decatur, Ill. The following, relating to improvements made by the Wabash R. R. appeared in Engineering Record, February 20, 1909. Mr. Cunningham, chief engineer, gives this cost: The cost of labor, supervision, etc., for operating for a period of 10 hours is $7. To this should be added depreciation charges, interest on the investment and cost of maintenance. The cost of the foundation and concrete receiving hopper was $1,225, and for the superstructure above foundation, $7,550, including the motive power and machinery, making the total $8,775. The interest charge of this investment at 5% would be $438.75. The depreciation should vary according to the length of time the plant is in service, so nothing should be charged for this for the first five years, but thereafter a charge of 5% per annum should be made. This means that the life of the plant is assumed to be 25 years. Maintenance charges will vary greatly and will increase as the plant grows older; 1% per annum should take care of this. Assuming these figures correct, then the cost of operating the plant will be $3,432.50 per year. As they are, on an average, 333 tons of coal per day handled by the plant, the cost for handling coal will be slightly less than 2.9 cts. per ton.

No charge has been made for switch engine service for transferring coal cars from the storage track to the depressed hopper.

The coaling chute, constructed of timber on concrete foundations, was designed with an elevated pocket that would hold 200 tons of coal, from which the engines could be coaled from ordinary movable aprons, and was constructed by the Fairbanks-Morse Co. Coal is brought to the chute in bottom-dump cars and is dumped into a concrete hopper beneath the track. From this hopper it is emptied under control of the operator by gravity into hoisting buckets through an orifice in each of the 2 side walls of the concrete hopper. There are 2 of these buckets, each with sufficient capacity for holding a ton of coal, and as 1 bucket is hoisted the other is lowered. The full bucket, on reaching the top, dumps automatically into the receiving bin. The whole plant is operated by an electric motor, controlled by 1 man, but 2 men in addition are necessary to empty the coal from the bottom-dump cars. It requires about 2½ hrs. to fill the bin provided no engines are taking coal during that time. But since engines are continually being coaled, it is necessary to operate the plant about 10 hrs., the capacity of the bin being sufficient to take care of the coal required during the other 14 hrs.

Cost of Erecting a Small Bucket Coal Elevator. The elevator, described by C. L. Samson in Engineering and Contracting, Aug. 30, 1911, was furnished and erected by contract for $1,280. The cost of fabrication in shop was about $750. The elevator casing came in 10 ft. lengths and weighed about 900 lbs. per section. It was erected section by section by means of gin pole erected on top of coal bunkers. Hoisting was done with double rope block to which was hitched a ½-ton Yale and Towne triplex chain block operated by hand. Naturally hoisting was intermittent, but considering the shortness of time actually consumed in hoisting, this loss of time did not amount to much.

As might be expected on a job of this size, the concrete work was quite high. The elevator belt was punched and buckets were attached on the job. There were 87 buckets and three bolts to each bucket.

The charge in detailed cost statement "Cutting batter off building wall" applies to the wall footing which projected out, preventing the elevator casing fitting up to wall.

The superintendent spent 15 days on the job, but actual work only lasted about 11 days, since there was a 4-days' delay waiting for material. One carpenter and four laborers did the work. The detailed costs were as follows:

Labor:	
Excavation at 25 cts. per hr.	$ 4.38
Making 2 stone drills	.50
Drilling holes for anchors	3.00
Cutting batter off of wall	4.00
Forms for concrete at 30 cts.	6.60
Shed for motor, at 30 cts.	2.70
Platform and railing, at 30 cts.	2.70
Concrete work at 25 cts., 7 yds.	14.50
Brickwork, at 25 cts.	3.88
Erection of steelwork	38.12
Belting and attaching buckets	5.00

Wiring and switchboard	6.60
Cleaning up debris	2.00
Total labor	$113.98

Materials:

9 bbls. Portland cement	$ 14.85
$2\frac{2}{3}$ cu. yds. sand	4.00
$5\frac{1}{3}$ cu. yds. crushed stone	10.66
450 brick	1.80
Total cost of material	$ 31.31
Total cost of erection — superintendence excluded	$145.29

Comparative Cost of Handling Locomotive Cinders by a Pneumatic Conveyor and from an Open Side Pit. Engineering and Contracting, Nov. 3, 1909, published data as determined by a 14-day test reported to the American Railway Bridge and Building Association, as follows: The track on which the cars were placed for receiving the cinders was on the same level with the engine track, and the cinders were dumped into the iron car below the track as shown in Fig. 17.

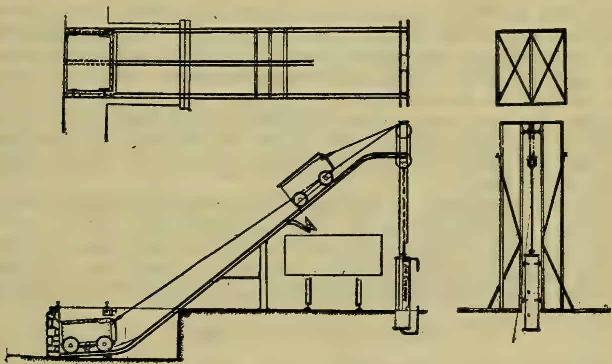


Fig. 17. Pneumatic cinder conveyor.

This car was then hauled up the incline by compressed air and automatically dumped the cinders into a gondola or a cinder dump. The incline was made of ordinary T-rails, and the character of the whole construction was such that the maintenance cost was very low. The drainage problem was simple because of the shallowness of the pit under the engine track.

Results of 14-day tests of this apparatus compared with an open side pit were as follows:

	Pneumatic conveyor	Open side pit
Switch engines	3	424
8 wheel simple engines	357	85
10 wheel simple and larger	716	56
Total	1,076	565

Average per day, 14 days	76.9	40.4
Number of men employed	12	4
Wages per day	$22.27	$7.44
Cost per engine (wages)	$0.29	$0.184
Number of cars of cinders loaded	30.75	13.75
Cu. yds. of cinders handled	1,417.6	207
Cost per cu. yd. of cinders handled	$0.22	$0.35
For each man employed, per day	8.4	5.3

The engines handled over the pneumatic conveyor were of heavy type, while those handled over the open side pit were largely switch engines and the others of lighter weight.

Cost of Ash Handling by Vacuum Conveyor in the Turkey Creek pumping station in Kansas City for $6.40 per day was less than by the former hand system, according to the last annual report of the Water Department, according to some notes in the Electrical World, Oct. 31, 1914, which also gives the following particulars: The plant installed removes ashes from the ash pits in the basement to a tank from which they feed by gravity into railway cars. The railroad pays $6 per car for the ashes. The guaranteed capacity of 250 lbs. per min. was exceeded in test by 20 lbs. Two men remove all ashes, load cars, clean the machine and take general care of the boiler-room basement. Costs of operation during 178 days were $712 for labor and $37.19 for repairs. Against this are receipts for $186 for 31 cars sold, a figure balanced by the estimated cost of power for running the machinery 3½ hrs. per day. By the old method 5 men and a mule would have cost $1,886.80.

Cost of Operating a Vacuum Ash-Handling System. C. O. Sandstrom in Power, July 7, 1914, gives the following:

Let us assume a plant of four 400-h.p. boilers, three of which are in constant operation at their rated capacities. With a boiler horsepower on 5 lbs. of coal and the ash content of the coal 12%, we would have

$$1200 \times 5 \times 0.12 = 720 \text{ lbs.}$$

of ashes per hour. Assuming the plant has ash hoppers with capacity sufficient for a day's operation, we would have

$$\frac{720 \times 24}{2{,}000} = 8.64 \text{ tons of ashes per day}$$

According to the reported test, seven tons of ashes were handled in an hour. This would require the services of two men to feed the ashes into the pipe — rapid work being necessary to prevent a waste of steam. With two men at 20 cts. an hour and working at the above rate, the labor charge per ton of ashes is

$$\frac{2 \times 20}{7} = 5.71 \text{ cents}$$

For a plant of this size, the apparatus completely installed would probably cost \$1,800, say, \$1,000 for the tank and \$800 for the piping. With 6% interest on an investment of \$1,800, this charge against a ton of ashes is

$$\frac{1{,}800 \times 0.06 \times 100}{365 \times 8.64} = 3.42 \text{ cents}$$

The depreciation of the ash tank is at least 8%. On an unlined tank it would be more, because of the corrosive action of the wet ashes. In either case, the baffle-plate would require frequent renewal. The depreciation of the ash pipe is high — fully 40%. The effect of ashes striking a bend in the piping while traveling at a high velocity can be appreciated only by those who have had experience with such things. At the above rates the depreciation charge per ton of ashes is

$$\frac{1{,}000 \times 0.08 + 800 \times 0.40}{365 \times 8.64} = \$0.1268 \text{ or } 12.68 \text{ cents}$$

Adding the foregoing, we have

$$5.29 + 5.71 + 3.42 + 12.68 = 27.10 \text{ cents}$$

as the cost of handling a ton of ashes.

To dispel any suspicion that the assumptions made are unwarranted, I will say that I had some experience with a vacuum ash-handling system in which the vacuum was maintained by a so called "positive blower" which was driven by a back-geared 50-h.p. motor. The average life of the manganese-steel wearing backs (2½ ins. thick) at the bends was 11 days. These wearing backs were replaced by plugged tees, but the power required to operate was such that the 50- was replaced by a 75-h.p. motor. The cost of handling a ton of ashes at this plant was 26 cts., exclusive of fixed charges. The system was abandoned for a mine car and skip hoist.

Gebhardt's "Steam Power-Plant Engineering" describes a vacuum ash-handling system like the one just referred to. It winds up with the statement that "the cost of handling the ashes in this installation is approximately 7 cts. per ton." Now, anyone working up the data given will find that the 7 cts. would no more than cover the cost of power, and does not include labor, maintenance or fixed charges.

W. W. Ricker in Power, Sept. 15, 1914, states that a conveyor having 7 tons' capacity per hr. would require a motor of from 15 to 30 h.p., never exceeding the latter unless of great length or having an unusual number of turns. The cost of electrical power varies with the locality and the conditions, but 5 cts. per ton is a fair average figure.

One man can easily feed 7 tons of ashes an hour to a conveyor under ordinary conditions. In many cases, the hoppers are under

the stoker hoppers, thus minimizing this labor. In most plants as small as the one under consideration, no extra labor is required as the regular fireman feeds the ashes to the conveyor, working a few minutes at a time at intervals during the day. One-half of Mr. Sandstrom's figure, or 2.8 cts. per ton, is ample.

In estimating the cost of complete installation, Mr. Sandstrom omits the motor and exhauster, which is more than fair to the conveyor manufacturer. A conveyor for such a plant as he describes would cost not less than $3,500, and with a large tank, under some conditions, might reach $4,500, including trenches, floor, plates, etc. Assuming as an average $4,000, the interest amounts to 7.6 cts. per ton.

Depreciation is the cost item which depends most largely upon the proper design, care and operation of a conveyor. Mr. Sandstrom's figure shows a depreciation of $400 per annum in the plant. I am familiar with a conveyor, built about eight years ago, where the repairs cost less than $15 per year. The motor is 25 h.p. and the amount of ashes handled considerably exceeds 8.64 tons per day. The tank, although unlined, has never been repaired, but is painted occasionally.

Another conveyor, in operation over four years, removes the ashes from ten 500-h.p. boilers; it has a 30-h.p. motor. The repairs, according to the user, have cost considerably less than $25 per annum. The conveyor has never been out of commission, and the engineer has since specified another conveyor which has been installed and is operating successfully.

A large conveyor, of 18 tons' capacity per hr., has been in operation for more than four years, handling from 40 to 50 tons per day at an annual cost for repairs of less than $50. This shows a cost under ½ ct. per ton of ashes handled.

A study of the records of a large number of plants shows that repairs vary from $10 to $300 per annum; cost of plants, from $3,500 to $10,000; ashes handled per year, from 3,000 to 20,000 tons. It is interesting to note that the highest repairs cost is frequently in smaller plants, probably because, where the amount of ashes is large, the removal is of sufficient importance to secure supervision of the conveyor.

In arriving at the cost of repairs, records from many plants show that $150 per annum is more than liberal for a plant of the size and capacity mentioned by Mr. Sandstrom. This amounts to 4.7 cts. per ton handled. The total cost as taken from the records of many plants, is as follows: Power, 5 cts.; interest, 7.6 cts.; labor, 2.8 cts.; depreciation, 4.7 cts.; cost per ton, 20.1 cts.

It is not my purpose to establish a fixed price per ton for ashes handled, as this will vary through wide limits with varying conditions. A cost of 25 cts. per ton for taking ashes hot from the pits and placing them quenched in cars or carts outside the boiler room is not excessive where the total amount is small.

CHAPTER VII

STEAM POWER

Definitions and Principles. The reader who is not familiar with the technical terms relating to power will do well to read pages 62 to 70 and pages 486 to 488.

Economic Value of Furnace Efficiency. Joseph Harrington gave Table I and Figs. 1–5 in a paper read before the Western Society of Engineers in Chicago.

The true boiler efficiency is not greatly affected by difference in the rate of heat absorption, but is controlled by ability to absorb heat, while furnace efficiency is affected by considerations of cleanliness. Under standard conditions of cleanliness the ability of a tube to transmit heat is practically invariable. Table I shows a number of heat balances which indicate a fairly constant boiler efficiency at a fair range of rating, the grate and furnace

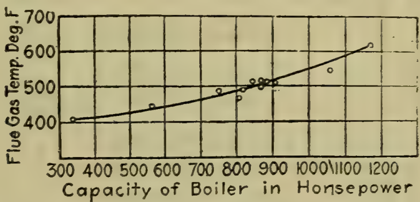


Fig. 1. Relation between boiler capacity and flue gas temperature.

efficiency being subject to an appreciable variation. For correct figures the analysis must be on the basis of heat contained in the fuel as fired, rather than upon either dry coal or combustible, and since the moisture contained in the coal has an influence on the efficiency of the entire process it must be taken into consideration.

The Middle Western coals may contain as high as 15% of moisture, lignites from 25 to 40% in which case an appreciable portion of the total heat value of the coal is used in evaporating this moisture. While Eastern coals show a closer relation between the actual and dry analyses, boiler tests with these coals must be analyzed on a basis of coal as fired.

Fig. 2 is plotted on the assumption that the net amount of heat in a pound of fuel is the difference between the percentage of moisture and 100, disregarding the ash for the time being, or con-

TABLE I. HEAT BALANCE PER POUND OF COAL FIRED — B.T.U.

		Absorbed by boiler		Necessary losses				Furnace and grate losses						Boiler losses				
Test	B.t.u. pound	Water	Steam	Moisture and H_2O from H	By dry gases up to temp.	Available for unit	Highest theor. efficiency	Comb in ash	Excess air to *Tp*	CO	Cinders	Available for boiler	Furnace and grate efficiency	By temp. gases above *Tp*	Air leakage	Radiation and unacc't for	Boiler efficiency	Comb. efficiency
1.	14,027	9534	866	391	655	12,981	92.6	319	89	0	290	12,283	94.6	483	854	546	84.7	74.1
2.	13,092	8668	765	450	696	11.946	91.3	405	193	56	190	11,102	92.9	941	406	322	84.9	72.0
3.	14,103	9089	831	447	713	12.943	91.8	332	523	155	290	11,643	90.0	680	311	732	85.2	70 3
4.	13,389	8557	803	427	667	12,295	91.8	557	339	121	290	10,888	89.4	576	196	856	85.2	69.9
5.	13.370	8671	749	471	624	12,275	91.8	479	460	0	290	11,046	90.0	658	273	695	85.2	70.4
6.	13,362	8706	734	487	707	12,168	91.1	594	175	110	290	10,999	90.4	424	349	786	85.9	70.7
	Heat balance in per cent.																	
1.	.....	....	...	...	...	.....	...	2.39	0.64	0.0	2.08	.....	94.6	3.47	6.13	3.92	84.7	74.1
2.	.....	....	...	...	...	.....	...	3.09	1.47	0.43	1.45	.....	92.9	7.19	3.10	2.46	84.9	72.0
3.								2.35	3.71	1.10	2.06	.....	90.0	4.82	2.21	5.19	85.2	70.3
4.	.....	....	...	...	...	.....	...	4.16	2.53	0.90	2.17	.....	89.4	4.30	1.46	6.39	85.2	69.9
5.	.....	....	...	...	...	.....	...	3.58	3.43	0.0	2.17	.....	90.0	4.90	2.04	5.20	85.2	70.4
6.	.....	....	...	...	...	.....	...	4.45	1.31	0.82	2.17	.....	90.4	3.17	2.61	6.88	85.9	70.7

sidering the ash percentage as constant. For instance, wet coal containing 20% of moisture would contain only 80% of combustible. Lignite coals containing 35% of moisture represent 9350 B. t. u. instead of 15,000 if the coal contained no moisture.

Experiment has shown that a moisture content of 25% is about the limit of practical usefulness with the ordinary furnaces in

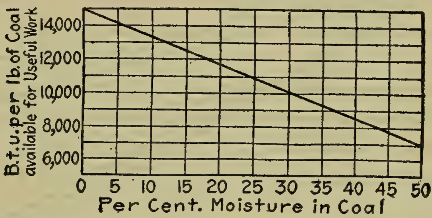


Fig. 2. Effect of moisture in coal on available heat.

commercial service. In excess of this lignites require a specially designed furnace.

For Western coal a gas analysis of 13% of CO_2 is about the limit of economic operation, because when it is carried much beyond this point, CO will develop and furnace efficiency on this account

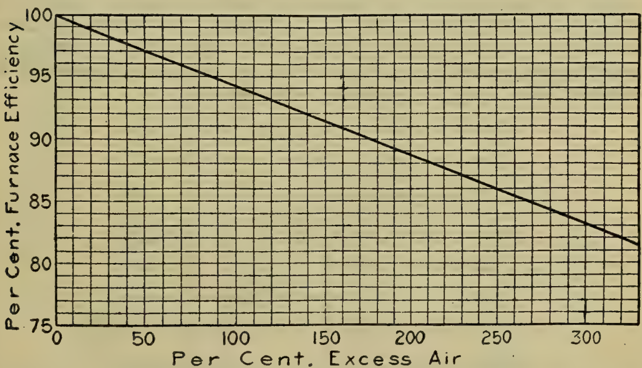


Fig. 3. Relation between furnace efficiency and excess air.

will not increase, the loss due to imperfect combustion being greater than the gain effected by reducing the excess air. A study of these effects is given in Figs. 3 and 4. Fig. 3 has been carried to the ordinary extent of dilution, and illustrates the result of a leaky fuel bed or porous setting.

Mr. Harrington says that from his experience it is most im-

portant to keep the CO in furnace gases down to a minimum and when this gas appears he stops the reduction of air supply even though the mixing ability of the furnace is deficient.

The deductions from Mr. Harrington's mathematics showing the

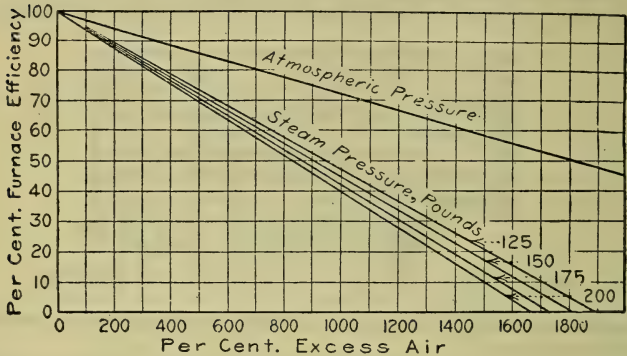


Fig. 4. Effect of excess air on furnace efficiency at different steam pressures.

method of determining the excess air and CO curves, are to the effect that each 100% of excess air affects the efficiency 5.62%, and that 1% of CO reduces furnace efficiency by 3⅓%. Ultimately the efficiency would be zero when the per cent. of CO reached 30, assuming that such a condition were possible.

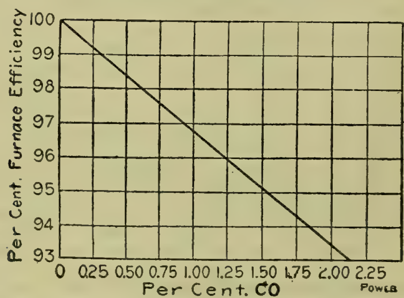


Fig. 5. Relation between furnace efficiency and loss from CO.

Relation between the Cost of Power and Load Factor for Steam Turbine Plants of 25,000 kw. Capacity and Larger. In a paper before the A. I. E. E. at the 30th Annual Convention, H. G. Stott and W. S. Gorsuch presented Fig. 6.

The authors state that in a first class steam plant using coal as fuel the cost per kw.-hr. net output varies approximately as the inverse 4th root of the load factor, this law holding between 15% and 90% load factors and being applicable to individual plants.

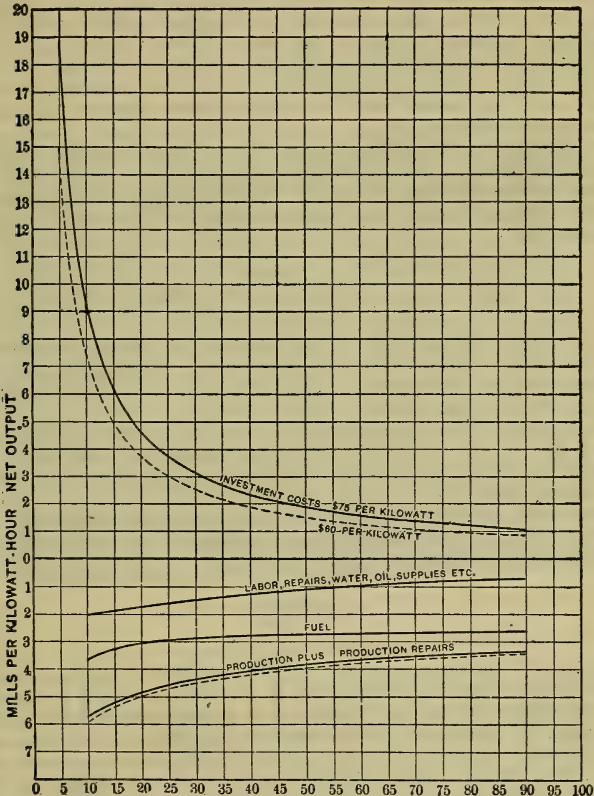


Fig. 6. Diagram showing the cost of power in its relation to load factor for steam turbine plants of 25,000 kw. capacity and larger. (14,000 B.t.u. per lb. of coal costing $3.00 per ton.

In the diagram the full line curves are for a steam plant operating at normal rating. The cost of equipment and building is taken at $75 and land at $6 per kw. economical rating. The dotted lines show the charges for a plant operating at the maximum 2-hour overload rating of the prime mover. Here the cost of equipment

and building is reduced to $60 and the land to $4.80 per kw. In each case the following allowances are made: Taxes 1%; interest, 5%; insurance 1%; amortization fund 3.5%; total investment charge of 10.5%.

The lower dotted curve shows the cost of production plus production repairs during the maximum hour periods when operating at maximum overload rating of 25% above economical rating. This is about 2.25% higher than the cost of economic operation.

Attention is called to the fact that if the two ordinates at any load factor are added, the toal cost of power appears less when operating at overload rating in spite of the increase in cost due to poor economy and overload, thus showing the marked influence of the investment costs on the total cost of power.

The investment cost curve which is an equilateral hyperbola, referred to its asymptotes as coordinates, (which are at right angles), is,

$$Y_1 = \frac{xy_i}{X}, \text{ in which}$$

Y_1 represents the investment cost in mills per kw-hr. net output, X the corresponding load factor of load expressed in %. xy_i the constants for any given curve, where x and y_i are the co-ordinates of any point on the curve.

To compute these investment costs of any plant for any load factor it will be necessary first to determine the value of xy_i in which x represents the present load factor and y_i the corresponding investment cost.

The curve showing the cost of production plus production repairs per kilowatt net output is an inverse fourth root curve and is represented by the equations,

$$Y_p = \frac{y_p \sqrt[4]{x}}{\sqrt[4]{X}}$$

in which Y_p represents the cost in mills per kw.-hr. net output, X the corresponding load factor of load in % and $y_p \sqrt[4]{x}$ a constant for any given curve, where x and y are the co-ordinates of any point on the curve. To compute the production plus the production costs of any station for any load factor, first determine the value of $y_p \sqrt[4]{x}$, where x is the present load factor and y_p the corresponding cost.

Illustration: If a plant is operating at 30% load factor with a cost of 4.4 mills for production plus production repairs and 3.1 mills for investment, making a total cost of 7.5 mills per kw. net output, what will be the cost if the plant were operated at 50% load factor?

Investment Cost

$$Y_1 = \frac{30 \times 3.1}{50} = 1.86 \text{ mills}$$

Production plus Production Repairs Costs

$$Y_P = \frac{4.4\sqrt[4]{30}}{\sqrt[4]{50}} = 3.87 \text{ mills}$$

Total cost of power per kw.
net output.......... 5.73 mills

Ratio of Boiler Horse Power to Station Capacity. In a paper for the 25th Convention of the A. I. E. E., J. R. Bibbins gives Fig. 7, showing the modern practice of proportioning boiler installation to

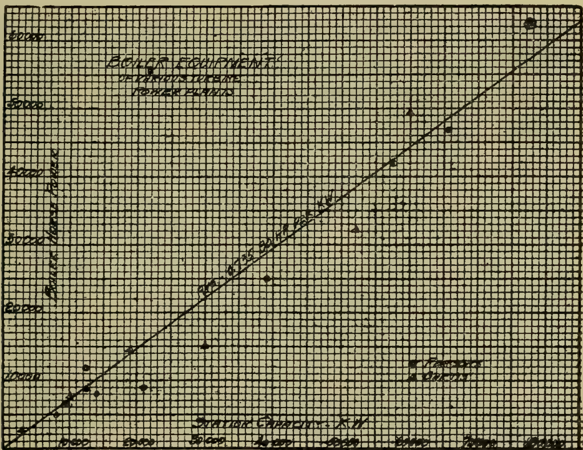


Fig. 7. Plot representing modern practice in boiler plant equipment.

station capacity and Fig. 8 the maximum battery capacity for various frontage widths.

Costs of Producing Power, Comparison of Estimated Costs with Those from Actual Tests. The following data for estimating the cost of power production, although based on the heating value of coal from a single state are from their nature of considerably more than just state-wide applicability. We therefore give them in much detail from a bulletin of the Iowa State College, where they were originally presented by H. W. Wagner, Assistant Engineer in Mechanical and Electrical Engineering:

In working up figures on the generation of steam power with Iowa coals no special attempt has been made to point out the most economical methods of operation. The object has been mainly to analyze the details and to show what the power costs per brake h.p. hr., delivered at the belt; and per kw.-hr., delivered at the switchboard, under the various common conditions of operation.

All assumptions are made to represent as nearly as possible the average practice in Iowa.

The conditions assumed as variable are the load factor, the number of hours the plant operates during the year, and the cost of coal. Depending upon these, variations then occur in nearly all items of expense which go to make up the cost of the brake h.p. and the kw.-hr.

The types of equipments for the different sized plants on Table II are chosen to represent not so much the more economical types for each size plant as the most practicable of those now in common

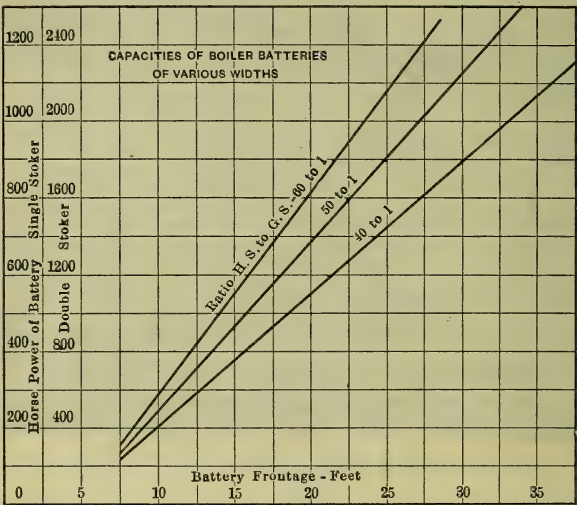


Fig. 8. Maximum battery capacity for various widths of frontage.

use in the state. The type for each case considered is listed in the schedule of equipment of plants on Table II. Table IV and attached notes give the sizes and types actually found operating in the state.

No attempt has been made to estimate or calculate the cost of electric power delivered to customers. That would involve the cost and upkeep of transmission lines, meters, etc. The initial cost as given includes nothing outside the power plant, proper.

The text and data in this bulletin have been worked out under the direction of W. H. Meeker, Mechanical Engineer, and F. A. Fish, Electrical Engineer, both of the Engineering Experiment Station.

Indicated horsepower is the mechanical power developed in the

engine cylinder by the steam working against the piston. It is measured from indicator cards taken from the engine cylinders.

Brake horsepower is the actual mechanical power delivered by the flywheel or pulley to the belt. It is measured by a Prony brake or by an absorption dynamometer and is always less than the indicated horsepower.

Kilowatt is a unit of electrical power equal to 1,000 watts.

1 h.p. equals 746 watts, or 0.746 kws.

Conversely, 1 kw. equals 1.34 h.p.

Horse-power-hour and *kilowatt-hour* are units of energy or work done by the respective power units in one hour's time.

Table II gives the estimated costs of producing mechanical and electrical power in Iowa with Iowa coals. A thesis by W. M. Wilson was used as a basis of these figures. This thesis was prepared from a large amount of data on costs and test runs collected by Mr. Wilson and presented by him for the professional degree of Mechanical Engineer at Sibley College of Cornell University, in 1904. The figures worked out in this thesis were compared with cost data from other authorities and wherever a fair comparison could be made, were found to check fairly well. The general difference seemed to be that the other authorities gave somewhat lower costs.

The estimates in the original thesis were based upon the following conditions:

Fuel: Heating value of 14,000 B. t. u. per lb., moist coal; 60% of heat in fuel absorbed by water in boiler.

Condensing Water: 30 lbs. water required to condense 1 lb. steam.

Cost: 1 ct. per 10,000 lbs. condensing water.

Fixed charges as a per cent. of the initial cost of plant:

Interest, 5%; depreciation, 5%; repairs, 2.5%; insurance, 0.5%; taxes, 1.0%; total, 14%.

Methods of operation:

First: 10 hrs. × 310 days = 3,100 hrs. per yr.
Second: 24 hrs. × 365 days = 8,760 hrs. per yr.

Only the second method has been given in Table II as reprinted here. Initial costs include duplicate feed pumps, one reserve engine and one reserve boiler, in addition to those required for rated load.

The cost of building for the horizontal engines and turbines was taken at $1.50 per sq. ft. This is approximately the cost of a steel frame building having brick walls and a fireproof roof. The price of land was taken at $0.50 per sq. ft.

Where condensers are not used it is assumed that feed water is taken from the heater at a temperature of 190 deg.; in the case of condensing engines it is taken at 160 deg., and where economizers are used, it is fed into the boiler at 280 deg.

When the plant is used only 10 hrs. per day, 310 days per yr., coal is required for banking fires and getting up steam before the

10-hr. period that the plant is in operation. An allowance of 5 lbs. of coal per boiler h.p. per day should be allowed for this purpose.

The load factor was taken at 100%, i. e., the plants are assumed to run at full load during the time of operation.

In the original thesis from 3 to 6 types of engines were given for each size of plant. In the following but one type was chosen for each plant of a given rated capacity; a different type was chosen for each different size of station, while at the same time an effort was made to choose that one which was the most typical of those producing power most cheaply.

In order to fit Iowa conditions the following additions and modifications were made before arriving at the final figures:

Cost and Heating Value of Fuels:

First case: $3 per 2,000 lbs., delivered, for coal with a heat value of 11,000 B. t. u., per lb., moist.

Second case: $2 per 2,000 lbs., delivered, for coal with a heat value of 9,000 B. t. u., per lb., moist.

Boiler Efficiency at 100% Load Factor:

60% of heat in 11,000 B. t. u. coal absorbed by water in boiler.
55% of heat in 9,000 B. t. u. coal absorbed by water in boiler.

With the above values the fuel cost of evaporating 1,000 lbs. of water from and at 212 deg. with the $3 coal is 22 cts.; with the $2 coal it is 19.6 cts.

Initial cost of boilers and settings is increased 20% because of the greater boiler and furnace areas required to get sufficient heat out of the lower grades of Iowa coal. This increase in cost of 20% is arrived at as follows:

The efficiency of boilers is assumed as 60% in the original calculations. Under Iowa conditions an average of 57.5% is assumed for the two low grades of coal.

$60\% \div 57.5\% = 104\%$, the ratio of efficiencies.

The heat value of coal in the original data is taken at 14,000 B. t. u. per lb. Under Iowa conditions the average of 9,000 and 11,000 is 10,000 B. t. u. per lb.

$14{,}000 \div 10{,}000 = 140\%$, the ratio of heat value in the coal.

$104\% \times 140\% = 146\%$, the ratio of weights of coal required to supply sufficient steam. In other words, 46% more Iowa coal under Iowa conditions must be burned than is estimated in the original data.

Assuming, roughly, that half of this increase in coal consumed is taken care of by a fast fire, the capacity of boilers and grates must be increased by 23%. This would then make an increased cost of the boilers and settings of about 20%.

Mechanical Efficiencies of Engines at 100% Load Factor:

	Per cent.
100 and 200 hp. reciprocating units	85.0
600 hp. reciprocating units	87.5
Turbines	90.0

Percentages of Expenses at Various Load Factors:

Load factor, per cent	100	75	50	25
Coal req., recip. engines......	100	87.5	75	62.5
Coal req., turbines	100	85	70	57.5
Condensing water	100	100	90	80
Attendance	100	100	100	100
Oil and waste	100	100	100	100

The above percentages represent the relative costs per rated indicated h.p. of plant and not per h.p. actually developed. For instance, the cost of coal for reciprocating engines per rated indicated h.p. is taken at 100% when the plant is running at 100% load factor or at full rated capacity. At 75% load factor when the average load is only 75% of the rated capacity, the coal required per rated indicated horsepower is 87.5% of that required at 100% load factor. In other words, the whole plant takes .875 as much coal to develop 75% of the rated load as it takes to develop full load.

The term "load factor" as used above, is the ratio between the average load and the capacity of the plant when both terms of the ratio refer only to the time operated. The same kind of load factor is used throughout on all data and curve sheets showing estimated power costs.

The above paragraph leads to the fact that more coal is required per h.p.-hr. at the lower load factors. This is true because of lower boiler and engine efficiencies when working at lower load factors or when the plant is under loaded. Oil and waste and attendance costs are assumed to be the same for the whole plant at all load factors. Reciprocating engines are assumed to take a greater percentage of coal at the low load factors than the turbines because their efficiency drops more rapidly. The above figures referring to the various expenses at different load factors were derived from a study of the tests and data from different authorities.

The figures given above as well as those on Table II describing the conditions considered are to represent first-class operation. Local conditions vary a great deal.

By comparing actual local conditions with those used above a closer estimate can usually be made for any specific case. For instance, in some plants the exhaust from non-condensing engines may be used for steam heating, the revenue from which will effect a lower cost of power. In other cases where the load factor is low, the cost of attendance may be cut down if the firemen can be used for other work during the period of low power demand. The price of coal delivered in the furnace room depends largely upon railroad facilities and varies much at different points. Poor firing or defective equipment adds greatly to the cost of producing power. This matter is discussed further.

The costs per kw.-hr. were figured from the costs per brake h.p. by adding to the total yearly expense on account of the added electrical machinery and by taking into account the different efficiencies of the electrical generation at the different load factors.

From Mr. Wilson's table initial costs of electrical generators were obtained and in the average case the fixed charges on these figure out to add about 8% to the total yearly expense. The following table of electric generator efficiencies was made up from a study of tests and from data of different authorities.

	%			
Load factor	100	75	50	25
Operated by 100 and 200 hp. engines	85	80	75	70
Op. by 400 and 600 hp. engines	87.5	83	79	75
Operated by 1,200 and 2,000 hp. engines	90	87	84	80

The figures at various load factors assume that the plant be operated so as to produce rated load at any time. The load factor is taken as the ratio of the average load to the full rated capacity of the plant, when both terms of the ratio refer only to the time during which the plant operates.

All figures dealing with fuel refer to moist coal. Moist coal with a heating value of 11,000 B. t. u. per pound corresponds to coal having 8.3% moisture and giving 12,000 B. t. u. per dry pound. Moist coal with a heating value of 9,000 B. t. u. per pound corresponds to coal having 10% moisture and giving 10,000 B. t. u. per dry pound.

Calculations of Power Costs for any Particular Plant.

The expense items have been separated somewhat to show how the final results have been reached. The separation of expenses is of value when the reader wishes to calculate costs where certain conditions are far from the ordinary. It is not supposed that any one plant will closely approach the "average" conditions as assumed in working out the figures on Table II. Large variations may occur in the initial cost of the plant, price of coal, or efficiency of machinery.

TABLE II. ESTIMATED COSTS OF PRODUCING POWER WITH IOWA COALS

Item No.	Per cent. load factor	24 hours per day — 365 days per year						
1. Rated i. hp. of plant	100	100	200	400	600	1,200	2,000	
2. Number of units	100	2	3	3	4	3	3	
3. Size of each unit, i. hp.	100	100	100	200	200	600	1.000	
4. Number of boilers	100	2	3	4	4	3	4	
5. Size of each boiler, hp.	100	92	74	88	113	230	256	
6. Brake hp. of plant	100	85	170	340	540	1,050	1,800	
7. Cost of engines, room and equipment	100	51.72	52.20	50.05	45.06	43.60	31.55	a
8. Cost of boilers	100	22.85	14.76	11.00	9.04	12.70	11.04	a
9. Cost of boilers, room and equipment	100	58.65	38.92	28.70	22.22	20.61	18.29	a
10. Total initial cost	100	110.37	91.12	78.75	67.28	64.21	49.84	a

Item No.	Per cent. load factor	24 hours per day — 365 days per year						
11. Fixed charges, 14% on initial cost	100	15.40	12.75	11.03	9.42	9.00	6.98	b
12. Oil and waste	100	2.89	2.89	2.89	2.89	2.89	2.89	b
13. Attendance	100	43.80	30.66	21.37	17.96	13.14	10.51	b
14. Condensing water	100	....	....	5.48	4.65	3.55	3.55	b
15. Boiler pressure, lbs. per sq. in.	100	100	120	120	120	150	150	
16. Lbs. of steam per i. hp.-hr.	100	30	24	20	17	13	13	
17. Lbs. water evaporated per lb. coal	100	6.4	6.4	6.4	6.0	6.0	6.8	c
18. Lbs. coal per i. hp.-hr.	100	4.65	3.74	3.34	2.83	1.92	1.92	c
19. Lbs. water evaporated per lb. coal	100	4.8	4.8	4.5	4.5	5.1	5.1	d
20. Lbs. coal per i. hp.-hr.	100	6.20	4.98	4.45	3.76	2.55	2.55	d
21. Cost of coal per i. hp.-yr.	100	61.30	49.30	44.10	37.20	25.40	25.40	c
22. Cost of coal per i. hp.-yr.	100	54.30	43.70	39.00	32.90	22.50	22.50	d
23. Total cost per i. hp.-yr.	100	123.39	95.60	84.87	72.12	53.98	49.33	c
24. do	75	115.71	89.44	79.35	66.44	50.80	45.52	c
25. do	50	108.07	83.27	73.28	60.51	47.28	41.36	c
26. do	25	100.37	77.16	67.31	55.37	43.73	37.82	c
27. Total cost per b. hp.-yr.	100	145.00	112.50	99.70	80.10	61.60	54.70	c
28. do	75	136.00	105.10	93.30	73.70	58.00	50.60	c
29. do	50	127.00	97.80	86.10	67.20	54.00	46.00	c
30. do	25	117.50	90.70	79.10	61.50	50.00	42.00	c
31. Cost per b. hp.-yr.	100	1.65	1.28	1.14	0.91	0.70	0.63	c
32. do	75	2.07	1.60	1.42	1.12	0.89	0.77	c
33. do	50	2.89	2.23	1.96	1.53	1.23	1.05	c
34. do	25	5.37	4.15	3.62	2.81	2.29	1.92	c
35. Total cost per i. hp-yr.	100	116.39	90.00	79.77	67.80	51.08	46.43	d
36. do	75	109.61	84.54	74.85	62.74	48.30	43.02	d
37. do	50	102.87	79.07	69.48	57.51	45.08	39.36	d
38. do	25	96.00	73.66	64.11	52.87	42.00	36.12	d
39. Total cost per b. hp.-yr.	100	137.90	106.80	94.75	75.80	58.64	51.75	d
40. do	75	129.80	100.13	88.90	70.05	55.45	48.15	d
41. do	50	121.75	93.61	82.36	64.20	51.80	43.95	d
42. do	25	113.06	87.20	75.55	59.04	48.20	40.30	d
43. Cost per b. hp.-hr.	100	1.57	1.21	1.08	0.87	0.67	0.59	d
44. do	75	1.96	1.52	1.36	1.07	0.85	0.74	d
45. do	50	2.77	2.13	1.88	1.46	1.18	1.00	d
46. do	25	5.16	3.98	3.47	2.70	2.16	1.85	d

Item No.	Per cent. load factor	24 hours per day — 365 days per year						
47. Cost per kw.-hr..	100	2.80	2.18	1.87	1.49	1.12	1.01	c
48. do	75	3.73	2.88	2.46	1.94	1.47	1.27	
49. do	50	5.55	4.28	3.57	2.78	2.11	1.80	
50. do	25	11.00	8.51	6.95	5.40	4.13	3.45	
51. Cost per kw.-hr.	100	2.67	2.06	1.77	1.43	1.07	0.95	d
52. do	75	3.53	2.74	2.36	1.85	1.40	1.22	
53. do	50	5.32	4.08	3.42	2.66	2.02	1.71	
54. do	25	10.55	8.15	6.66	5.18	3.89	3.33	

a Per i. hp. *b* Per i. hp. year. *c* Coal at $3. *d* Coal at $2.

EXPLANATIONS OF ITEMS ON TABLE

The left-hand margin of Table II shows which general items are figured at 100% load factor. The right-hand margin shows on what basis the general costs are figured and with what price of coal each particular cost is figured.

All costs are given in dollars except those for brake hp.-hours and kw.-hrs., which are given in cents.

Item 1 gives the rated indicated hp. of the plant upon which the yearly expenses are calculated.

Items 2, 3, 4 and 5 show the actual number and rated capacity of engines and boilers, including one reserve engine and boiler in each plant. It may be noted that for the larger plants the rated hp. of boilers is low when compared with the engine hp. This is explained by the fact that the larger engines require less steam per hp. hour.

Item 6 gives the estimated brake hp. of the plant, which represents the actual mechanical horsepower delivered by the flywheel to engine belt at full rated capacity.

Item 7 includes the cost of engine room and everything in it except the electrical machinery.

Items 7-10 give the costs per rated indicated hp.

Item 9 includes the cost of stack, boiler room and everything in the boiler room.

Items 11–14 give the yearly expenses per rated indicated hp.

Item 10 includes the entire cost of plant per rated indicated hp., exclusive of the electrical machnery.

The electrical machinery is not considered before item 47 because the object is first to arrive at a cost of purely mechanical power.

Item 17 gives the lbs. of water evaporated per lb. of moist fuel. These amounts vary with constant boiler efficiency because of the different temperatures at which the water is fed to the boiler.

The costs per indicated hp. year and per brake hp. year are based upon the rated indicated hp. and brake hp. respectively, and not upon the power actually developed at the various load factors below 100%.

The costs per brake hp.-hr. and per kw.-hr. are based upon the power actually delivered to the belt and to the switchboard respectively.

100 i. hp. plant: Simple, non-condensing, high-speed engines. Fire-tube boilers.

200 i. hp. plant: Compound, non-condensing, high-speed engines. Fire-tube boilers.

400 i. hp. plant: Compound, condensing, high-speed engines. Fire-tube boilers.

600 i. hp. plant: De Laval turbines. Fire-tube boilers.

1,200 i. hp. plant: Horizontal, condensing, low-speed Corliss engines. Water-tube boilers.

2,000 i. hp. plant: Parson's turbines. Water-tube boilers.

By comparing the items of expense in an actual case with those given for the corresponding "estimated" case, a net difference of costs will be obtained. Then by adding or subtracting (as the case may call for) this net difference from the "estimated" cost per rated indicated h.p. year a new cost per rated indicated h.p. year for the "actual case" will be obtained. This "actual" total cost, divided by the "estimated" total cost, will then form a ratio of total costs. This ratio multiplied by the "estimated" costs per brake h.p.-hr. or per kw.-hr. given for the corresponding case, will give the calculated costs for producing these units of energy under the "actual" conditions.

CURVE SHEETS

Figs. 9, 10, 11 and 12 are curve sheets showing graphically the estimated costs per brake h.p.-hr. for 10 and 24-hr. operation, with 9,000 B. t. u. coal at $2 and with 11,000 B. t. u. coal at $3, all with 100%, 75%, 50% and 25% load factors. Curves on Figs. 9 and 10 are plotted from items 31 to 34 of Table II. Curves on Figs. 11 and 12 are plotted from items 43 to 46 of Table II.

Figs. 13 to 28 constitute a second set of curve sheets showing estimated costs per brake horsepower with coals costing from $1 to $6 per 2,000 lbs. These curves show also the cost of coal per brake h.p.-hr. as separated from all other costs. The curve bordering the upper side of the shaded portion represents the total of all expenses except that of coal. Each of the upper curves represents the total cost with coal at the particular price with which the curve is marked.

For example, suppose one wishes to find the total cost and the fuel cost per brake h.p. in a 1,200 h.p. plant operating 10 hrs. per day, 310 days per yr., at 250 load factor, with 9,000 B. t. u. coal costing $3 per 2,000 lbs.

Turning to Fig. 20 which corresponds to the conditions given, it is seen that the "$3.00" curve indicates 3.5 cts. as the total cost per brake h.p.-hr. Dropping down to the curve bordering the shaded portion, it is seen that 2.15 cts. is the total cost per brake h.p. exclusive of coal. Subtracting 2.15 cts. from 3.5 cts. leaves 1.35 cts. per brake h.p.-hr. due to coal.

Table III gives the figures from which these curves were plotted. The costs to be added for each dollar that the coal cost per 2,000 lbs. are given to be used in calculations where the cost per 2,000 lbs. is not in even dollars.

It will be noticed that Table III has the same arrangement of conditions as has Table II. Table III also has an index of figure numbers referring to curve sheets corresponding to each particular condition.

TABLE III. TOTAL COST IN CENTS PER BRAKE HP.-HR.

Fig. No.	Load factor %	10 hrs. × 310 days Rated i. hp. of plant 100	200	400	600	1,200	2,000	Fig. No.	24 hrs × 365 days Rated i. hp. of plant 100	200	400	600	1,200	2,000	
5....	100	$0.31	$0.25	$0.22	$0.18	$0.13	$0.12	13....	$0.27	$0.22	$0.20	$0.16	$0.11	$0.10	9,000 B.t.u. coal.
		1.21	.94	.82	.66	.55	.47		.83	.62	.54	.44	.37	.31	
6....	75	.36	.28	.26	.20	.14	.13	14....	.32	.26	.24	.18	.13	.12	
		1.62	1.26	1.09	.88	.74	.62		1.11	.83	.71	.58	.49	.40	
7....	50	.46	.37	.33	.25	.19	.17	15....	.41	.33	.30	.22	.17	.15	
		2.43	1.88	1.62	1.31	1.09	.92		1.65	1.24	1.06	.86	.73	.59	
8....	25	.77	.62	.56	.40	.31	.28	16....	.68	.55	.49	.36	.28	.25	
		4.85	3.75	3.21	2.61	2.17	1.83		3.31	2.48	2.13	1.72	1.46	1.18	
9....	100	.41	.33	.30	.23	.17	.16	17....	.37	.30	.27	.21	.15	.14	11,000 B.t.u. coal.
		1.21	.94	.82	.66	.55	.47		.83	.62	.54	.44	.37	.31	
10....	75	.48	.39	.35	.27	.20	.18	18....	.42	.35	.33	.24	.18	.17	
		1.62	1.26	1.09	.88	.74	.62		1.11	.83	.71	.58	.49	.40	
11....	50	.62	.49	.45	.33	.25	.23	19....	.55	.45	.41	.30	.22	.21	
		2.43	1.88	1.62	1.31	1.09	.92		1.65	1.24	1.06	.86	.73	.59	
12....	25	1.03	.85	.74	.55	.43	.38	20....	.93	.75	.67	.49	.35	.33	
		4.85	3.75	3.21	2.61	2.17	1.83		3.31	2.48	2.13	1.72	1.46	1.18	

The lower figures in each line are the costs exclusive of coal. The upper figures in each line represent the amounts to be added for each dollar that the coal costs per 2,000 lb.

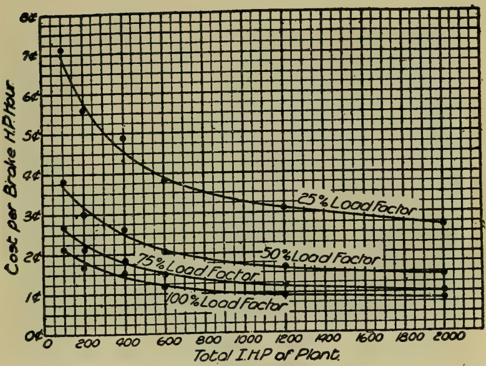


Fig. 9. Ten hours per day, 310 days per year, 11,000 B.t.u., coal at $3.00.

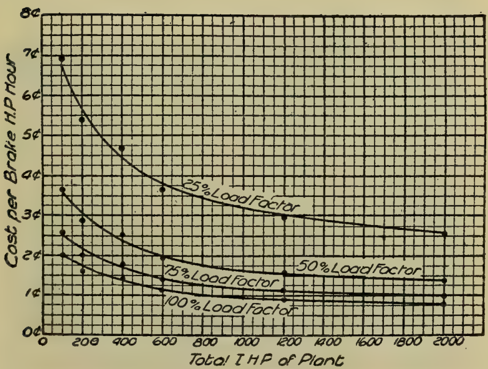


Fig. 10. Ten hours per day, 310 days per year, 9,000 B.t.u., coal at $2.00.

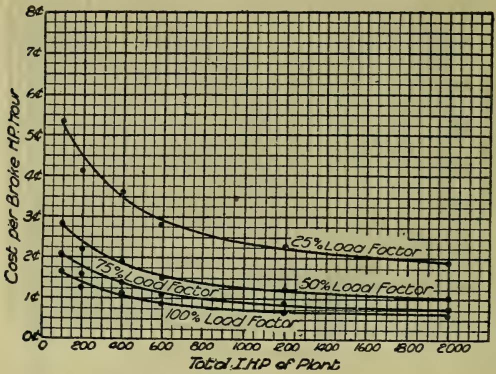


Fig. 11. Twenty-four hours per day, 365 days per year, 11,000 B.t.u., coal at $3.00.

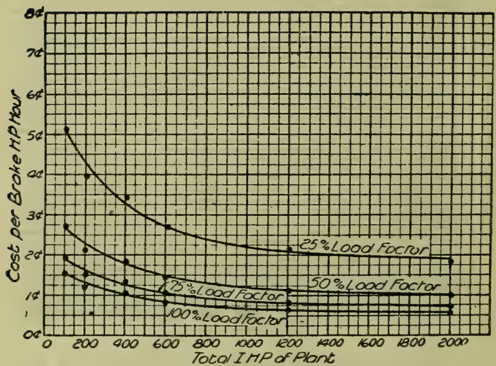


Fig. 12. Twenty-four hours per day, 365 days per year, 9,000 B.t.u., coal at $2.

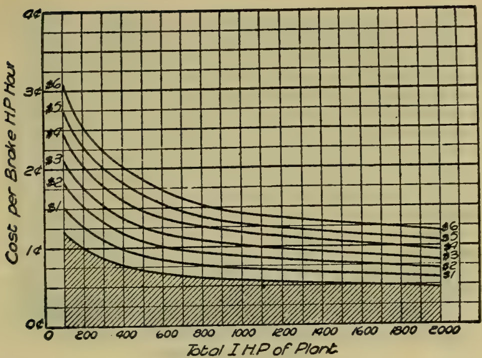


Fig. 13. Ten hours per day, 310 days per year, 11,000 B.t.u., coal, 100 per cent. load factor.

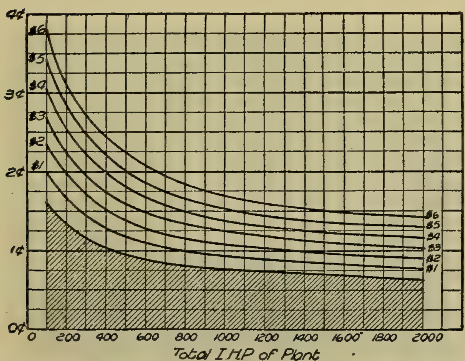


Fig. 14. Ten hours per day, 310 days per year, 11,000 B.t.u., coal, 75 per cent. load factor.

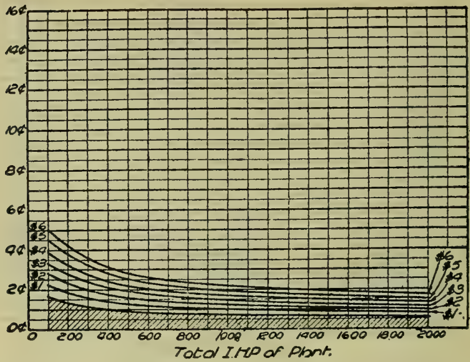


Fig. 15. Ten hours per day, 310 days per year, 11,000 B.t.u., coal, 50 per cent. load factor.

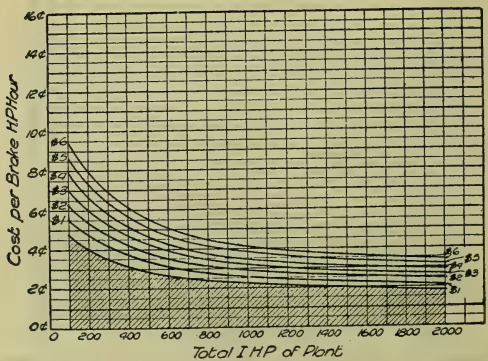


Fig. 16. Ten hours per day, 310 days per year, 11,000 B.t.u., coal 25 per cent. load factor.

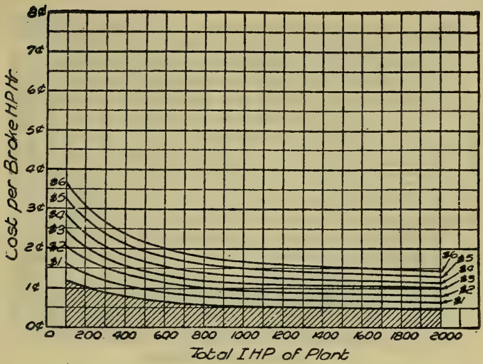


Fig. 17. Ten hours per day, 310 days per year, 9,000 B.t.u., coal, 100 per cent. load factor.

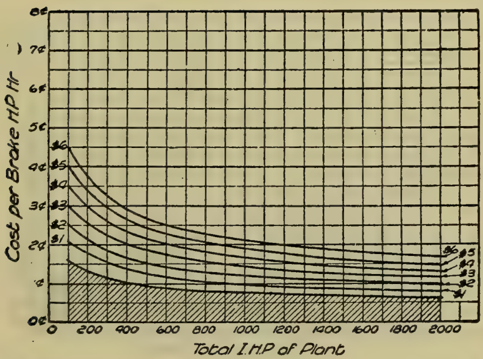


Fig. 18. Ten hours per day, 310 days per year, 9,000 B.t.u., coal, 75 per cent. load factor.

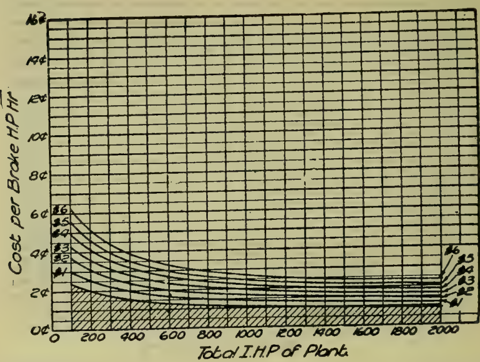


Fig. 19. Ten hours per day, 310 days per year, 9,000 B.t.u., coal, 50 per cent. load factor.

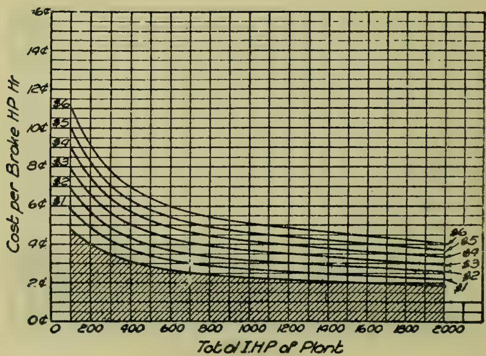


Fig. 20. Ten hours per day, 310 days per year, 9,000 B.t.u., coal, 25 per cent. load factor.

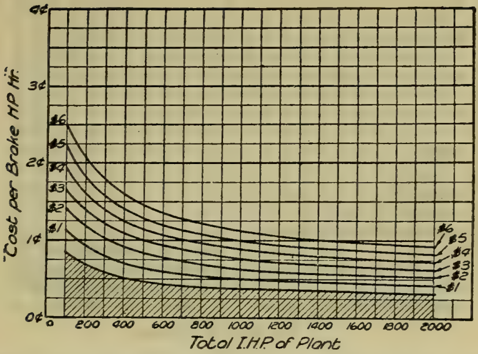


Fig. 21. Twenty-four hours per day, 365 days per year, 11,000 B.t.u., coal 100 per cent. load factor.

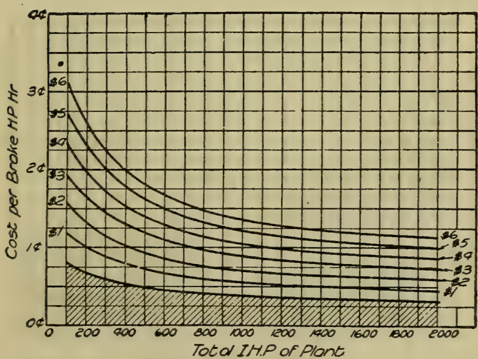


Fig. 22. Twenty-four hours per day, 365 days per year, 11,000 B.t.u., coal, 75 per cent. load factor.

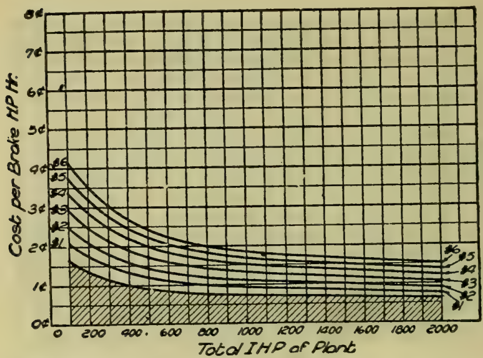


Fig. 23. Twenty-four hours per day, 365 days per year, 11,000 B.t.u. coal, 50 per cent. load factor.

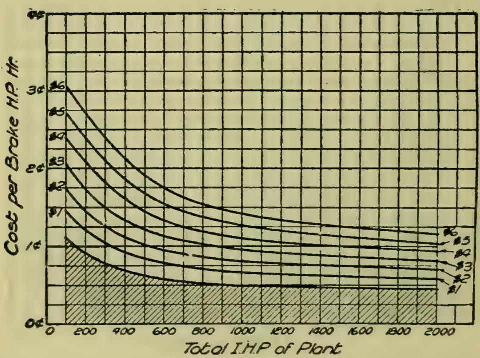


Fig. 24. Twenty-four hours per day, 365 days per year, 11,000 B.t.u., coal, 25 per cent. load factor.

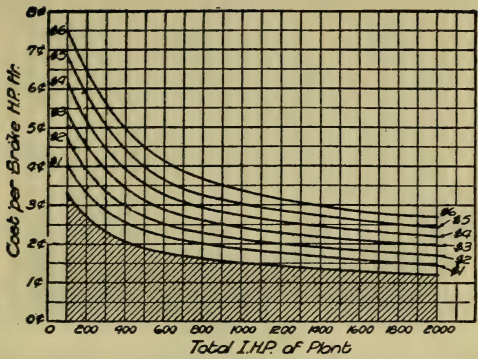


Fig. 25. Twenty-four hours per day, 365 days per year, 9,000 B.t.u. coal, 100 per cent. load factor.

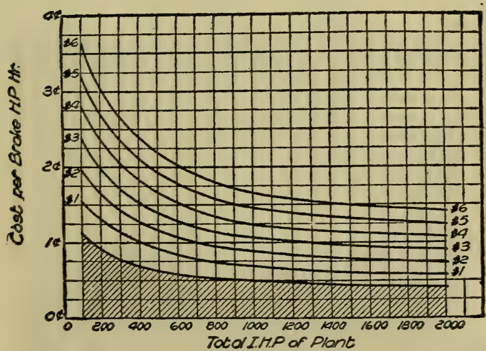


Fig. 26. Twenty-four hours per day, 365 days per year, 9,000 B.t.u. coal, 75 per cent. load factor.

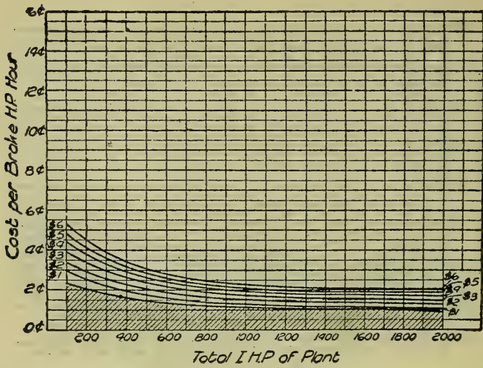


Fig. 27. Twenty-four hours per day, 365 days per year, 9,000 B.t.u. coal, 50 per cent. load factor.

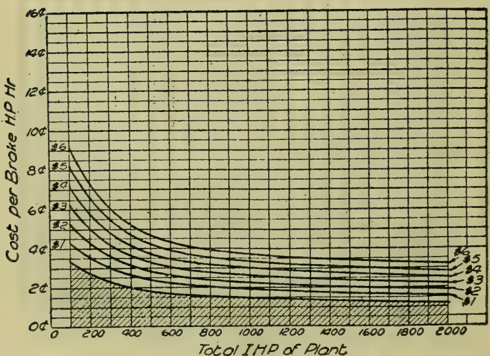


Fig. 28. Twenty-four hours per day, 365 days per year, 9,000 B.t.u. coal, 25 per cent. load factor.

TABLE IV. COSTS OF PRODUCING POWER BASED ON ACTUAL TESTS WITH IOWA COALS

1. Plant no.	1	2	3	4	5	6	7	8	9	10	Ave.
2. Year of test	1907	1908	1907	1909	1908	1906	1907	1912	1912	1910	....
3. Hr. operated per day	16	11	24	18	24	12	15	24	24	12	18
4. No. of engines operated	1	1	2	2	1	1	2	1	2	1	....
5. Total i. hp. of engines operated	80	100	115	120	150	165	200	250	375	750	230.5
6. No. of boilers operated	2	1	2	2	1	2	2	1	2	2	....
7. Total hp. of boilers operated	200	100	140	110	200	200	200	150	400	1,000	270
8. Total cost of plant	....	8,000	8.027	6,000	20,000	20.000	11,800	16.550	25,400	25,000	15,600
9. Total cost of plant, per i. hp.	....	80	70	50	133	121	59	66	67	33	75.50
10. Total cost of plant, per b. hp.	....	102	88	65	173	155	72	86	75	35	94.60
11. Fixed charges per i. hp. year	....	10.40	10.40	9.00	17.70	14.20	10.70	7.45	9.05	4.60	10.35
12. Operating expenses per i. hp. year	....	23.70	48.60	30.00	29.10	25.00	26.30	29.90	33.05	11.40	28.50
13. Total expenses per i. hp. year	....	34.10	59.00	39.00	46.80	39.20	37.00	37.35	42.10	16.00	38.85
14. Cost of coal per 2,000 lb. delivered	2.17	2.22	2.00	3.70	3.50	1.80	2.36	1.65	2.74	1.51	2.36
15. B.t.u. per lb. moist coal	8,750	10,250	8,850	12,900	11,440	9,800	10,280	8,950	11,000	9,320	10,150
16. B.t.u. per lb. dry coal	9,700	11.525	9,670	13.550	13,800	10,300	11,460	9.870	11.980	10,160	11,200
17. Boiler pressure — gauge	90	70	77	100	100	57	90	80	125	105	90
18. Lb. of steam per actual i. hp.-hr.	46.4	42	34	39	29	34	39	35.5	33	23	35.5
19. Lb. of water evap. per lb moist fuel.	4.7	6.0	4.1	6.4	4.7	5.7	5.7	4.8	7.87	4.5	5.47
20. Equip. evap. from and at 212 deg. per lb. moist fuel	5.1	6.2	4.6	6.9	5.1	6.0	6 3	5.1	8.0	5.1	5.85
21. Efficiency of boiler and grate (%)	57	47	46	52	44	53	53	47	65	50	51.4
22. Efficiency (%) of conversion	62	55	60	53	50	56	73	53	81	70	61.3
23. Efficiency (%) of plant — coal pile to sw'b'd	1.7	1.33	1.9	2.0	1.83	2.6	2.62	3.24	2.59	3.9	2.37
24. Load factor, based on peak — Time operated	.50	.57	.45	.54	.26	.53	.47	.47	.38	.62	.489
25. L.f. based on i. hp.— 365 days — Time operated	.37	.32	.37	.25	.23	.36	.40	.21	.27	.30	.31
26. L.f. based on i. hp.— 365 days — 24 hrs. per day	.25	.15	.37	.19	.23	.18	.25	.21	.27	.15	.22
27. Average i. hp. during run	30	32	43	30	35	59	80	53	101	285	74.8
28. Cost per actual i. hp. hr.	2.4	2.5	1.9	2.4	2.3	2.5	1.65	2.0	1.8	0.96	2.04
29. Average b. hp. during run	24	25	34	23	27	46	67	41	91	240	61.8
30. Cost per b. hp. hr.	3.0	3.2	2.4	3.1	3.0	3.2	2.0	2.6	2.0	1.15	2.58
31. Average kw. during run	13.9	13.1	19.2	11.9	13.1	24.7	43.5	21.0	61.2	148.5	37.0
32. Cost per kw.-hr.	5.15	5.85	4.25	6.0	6.15	5.86	3.13	5.0	3.0	1.85	4.62

EXPLANATION OF ITEMS ON TABLE IV

All costs are given in dollars except those for indicated h.p.-hrs., b.h.p.-hrs., and kw.-hrs., which are given in cents.

Items 4, 5, 6 and 7 give the number and ratings of only those engines and boilers actually operated in the test runs. Any reserve units are mentioned in the notes of equipment. Items 8, 9 and 10 include the cost of any reserve machinery and the costs per h.p. are obtained by dividing the total costs by the rated h.p. of the engines actually operated.

Item 11 gives the fixed charges per indicated h.p. year and includes interest, depreciation, repairs, insurance and taxes. Expressed as a percentage of the total initial cost, this item varies from 11.3% in the case of plant No. 8 to 18% in the case of plant No. 4.

Item 21, boiler and grate efficiency, gives the per cent. of heat in the coal actually absorbed by the water in the boiler.

Item 22, efficiency of conversion, is the ratio of the energy delivered at the switchboard to that given the engine piston by the steam.

Item 23, efficiency of plant, is the ratio of the energy delivered at the switchboard to that in the coal as fired.

Item 24 is the load factor or ratio between the average load and the peak load when both terms of the ratio refer only to the time during which the plant was operated.

Item 25 is the load factor or ratio between the average load and the rated capacity of the plant when both terms refer only to the time during which the plant was operated.

Item 26 is the load factor or ratio between the average load and the rated capacity of plant when the first term of the ratio refers to the time operated and the second term refers to 24 hours operation per day.

All three kinds of load factors are figured from the indicated h.p. of engines and are based upon 365 days operation per year.

Item 27 is the average indicated h.p. developed as figured from the indicator cards taken during the test.

Item 29, average brake h.p., is figured from the average indicated h.p. by assuming approximately equal losses of conversion in engine and generator.

Item 31, average kws., was figured from the switchboard instrument readings.

In the case of the turbo-generator in plant No. 10, the efficiency of conversion was figured at about 70% for the test load. The rating of 750 indicated h.p. was figured from the 500 kw. rating by assuming an efficiency of conversion of about 90% at full load. The load factors for this same plant were figured from the kws.

EQUIPMENT OF PLANTS TESTED

Plant No. 1.

1 simple engine, 80 h.p.
2 boilers, 100 h.p. each.
Feed water heater.
No reserve units.

Plant No. 2.

1 high speed engine, simple, 100 h.p.
1 boiler, 100 h.p.
Feed water heater.
1 reserve boiler, 100 h.p.

Plant No. 3.

1 simple engine, 70 h.p.
1 simple engine, 45 h.p.
2 boilers, 70 h.p. each.
No reserve units.

Plant No. 4.

1 Corliss engine, 100 h.p., run 5 hrs. per day.
1 Corliss engine, 20 h.p., run 13 hrs. per day.

1 boiler, 60 h.p.
1 boiler, 20 h.p.
Feed water heater.
No reserve units.

Plant No. 5.

1 compound engine, 150 h.p., run from 3 P. M to 12 midnight, and from 5A. M. to 10 A. M., making 14 hrs. of service per day for engine.
1 boiler, 200 h.p., fire kept banked while engine was not running.
1 reserve engine, 75 h.p.
Storage battery used as auxiliary to provide 24-hr. service.

With the same boiler efficiency a lower priced steam coal would have reduced the kw.-hr. cost from 6.15 to 5.2 cts.

Plant No. 6.

1 simple Corliss engine, 165 h.p.
2 boilers, 100 h.p. each.
Feed water heater.
No reserve units.

Plant No. 7.

1 Corliss engine, 120 h.p.
1 Corliss engine, 80 h.p.
1 boiler, 120 h.p.
1 boiler, 80 h.p.
No reserve units.

Plant No. 8.

1 Corliss engine, 350 h.p.
1 boiler, 150 h.p.
Feed water heater.
1 reserve engine, 75 h.p.
1 reserve boiler, 125 h.p.

Plant No. 9.

1 tandem compound engine, 225 h.p.
1 simple engine, 150 h.p.
2 boilers, 200 h.p. each.
Feed water heater.
1 reserve engine, simple, 120 h.p.

Plant No. 10.

1 Curtis vertical condensing steam turbine, 500 kw.
2 boilers, 500 h.p. each.
No reserve units.

The indicated horse power of the steam turbine is used as 750 on the data sheet. This figure is obtained by assuming a conversion efficiency of about 90% at full load.

POWER PLANT TESTS IN IOWA

Table IV gives results of tests on Iowa power plants and supplies approximate figures on the cost of generating power in Iowa with Iowa coals in electric power plants of the capacities noted on data sheet.

All figures are based upon a one day's test of each respective plant and upon the assumption that the plant is operated the same each day of the year. These tests were practically all run during the winter months and under the ordinary load conditions. The readings were taken and the results calculated by students of the Iowa State College under the direction of instructors in the Mechanical and Electrical Engineering departments of the college. These figures were arranged and reduced to a comparative basis by the Engineering Experiment Station.

The costs arrived at are not claimed to be entirely accurate. The greatest discrepancy would perhaps be in the valuation of the power plant or in fixing the operating expenses. It will be noted that the estimated value per rate indicated horsepower ranges from $50.00 to $133.00 for plants of 200 i.h.p. or under.

Only the engines and boilers actually used in the tests are given in the table. Any reserve units are mentioned in the notes on equipment. The total cost of plants, however, includes the reserve units.

The pounds of steam per i.h.p.-hr. represent dry steam and include that used for auxiliaries in practically all cases.

Efficiency of conversion is the combined mechanical efficiency of the engine and the efficiency of the electric generator.

All costs are based upon 365 days of operation per year.

The cost per b.h.p.-hr. is calculated from the cost per i.h.p.-hr. by assuming approximately equal losses of conversion in the engine and generator.

The cost per b.h.p.-hr. includes fixed charges on the electrical equipment of the station, while on Table II it does not. The difference amounts to about 8 or 10%.

COMPARISON OF DATA ON TABLES II AND IV

The results of actual tests are given to show how the estimated efficiencies and costs check with those found in actual practice. A very direct comparison is difficult to make because of the irregularities in cost of plants, hours of operation, load factors and types of equipment. Also most of the tests were made on plants of small capacities.

The point of load factors should receive special attention. There is some disagreement among engineers as to the correct definition of load factor. To avoid misunderstanding on this point, load factors based upon different standards are given together with a definition of each.

On Table II (estimated costs) the different percentages of load factor are based upon a peak load which is assumed to equal the full rated capacity of plant. On Table IV (actual costs) the peak load was found to be below the rated capacity in all cases.

If the load factor based upon the rated capacity in the actual tests is used as a basis for comparison, the cost per unit of energy is found to be considerably below the estimated costs. But if the factor based upon the actual peak load is used, the actual check quite closely with the estimated costs. On Table II the operating expenses are put at a price which assumes the ability to produce a peak load of rated capacity at any time. On Table IV the operating costs are at a price which insures the ability of the plant to produce not rated load but the actual peak load at any time. From this then, it appears that the most logical load factor to use is the one based on the actual peak load of the day. The following comparisons are made upon this principle.

The estimated costs assume two methods of operation as regards hours operated per year. The first assumes 10 hrs. per day, 310

days per yr. The second assumes 24 hrs. per day, 365 days per yr. The first is of value in getting at the cost of power for factories operating only 10 hrs. per day and 6 days per week. The second is of value in getting at the cost of all classes of power supplied every hr. of the year. Most electric central stations operate every day of the year, although many run less than 24 hrs. per day. Referring to Table IV it will be noticed that for the plants as tested the average number of hrs. operated per day is 18.

The following is a comparison between the averages of the actual tests and the figures of the nearest corresponding estimated case.

	Actual.	Estimated
Hrs. per year	6,570	8,760
I.h.p. of plant	230.5	200
Total cost per i.h.p.	$75.50	$91.12
Fixed charges per i.h.p.-yr.	$10.35	$12.75
Operating cost per i.h.p.-yr.	$28.50	$66.32
Total cost per i.h.p.-yr.	$38.85	$79.07
Cost of coal per 2,000 lbs.	2.36	$2.00
B.t.u. per lb. moist coal	10,150	9,000
Load factor	.489	.50
Average brake h.p. developed	61.8	85.0
Cost per brake h.p.-hr., cts.	2.58	2.13
Average kws. developed	37.	47.5
Cost per kw.-hr., cts.	4.62	4.08

The greatest difference in the above comparison is with the operating expenses per rated horse power year. It is much lower in the "actual" column than in the "estimated" column because in the first case the plant is so operated as to produce a maximum load of only about two-thirds the rated load, while in the second case the plant is so operated as to produce the full rated load at any time. Also in the first column, the time operated is but 75% of that in the second.

The costs per unit of energy are slightly higher in the "actual" column than in the "estimated" column, but the average hrs. operated is only 75% of the time operated in the "estimated" column, which would naturally tend to make an even greater difference than that shown.

By a general comparison of all figures, the estimated costs seem to be higher than those figured from the actual tests in Iowa power plants; this is especially true as the load factor decreases. It is possible, however, that in the case of the tests certain operating expenses were omitted, such as management and bookkeeping.

Following is the relationship between some additional corresponding items on Tables II and IV.

Table II — Steam consumption ranges from 13 to 30 lbs. per i.h.p.-hr.

Table IV — Same ranges from 23 to 46.4.

Table II — Boiler pressure ranges from 100 to 150 lbs. per sq. in. by gage.

Table IV — Same ranges from 57 to 125.

Table II — Efficiency of boiler and grate ranges from 55 to 60%.

Table IV — Same ranges from 44 to 65%.

Table II — Water evaporated per pound moist coal ranges from 5.3 to 6.8 lbs.

Table IV — Same ranges from 4.1 to 7.87.

Table II — Pounds of coal per indicated h.p.-hr. ranges from 1.92 to 7.0.

Table IV — Same ranges from 4.2 to 9.9.

Table II — Efficiency of conversion ranges from 49 to 81%.

Table IV — Same ranges from 50 to 81%.

Table II — Cost of coal per million B.t.u. ranges from 11.1 to 13.6 cts.

Table IV — Same ranges from 8.1 to 15.3 cts.

Note.— In all the above comparisons, except efficiency of conversion, the figures are taken from Table II at 100% load factor, and from Table IV at whatever load factor occurred in each case. Efficiency of conversion was taken from the extreme limits in both cases.

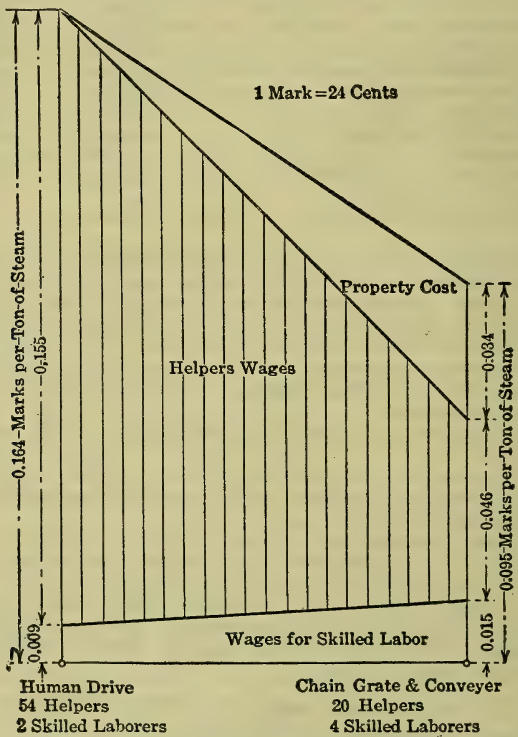


Fig. 29. Reduction of steam cost in boiler house by elimination of human labor.

Reduction of Steam Cost in Boiler House by Elimination of Human Labor. Fig. 29 shows graphically the economic results of the adoption of coal conveyors and automatic stokers, and was

included in a paper communicated to the Society of German Engineers by Professor Kammerer, and reprinted in Power and the Engineer, November 8, 1910.

Before the introduction of mechanical means, there were required

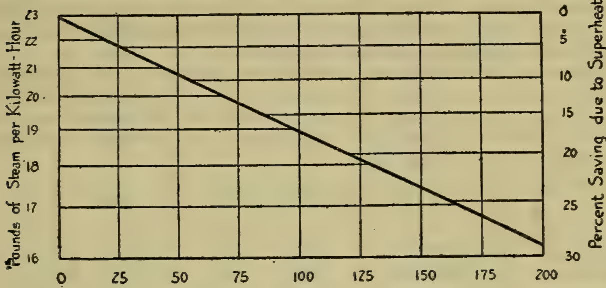


Fig. 30. Per cent. of saving due to superheat.

in the plant under investigation, 54 firemen and 2 overseers, necessitating an outlay in wages of 3.9 cts. per ton of steam. Afterward, only 20 firemen, 2 overseers and 2 machinists were needed.

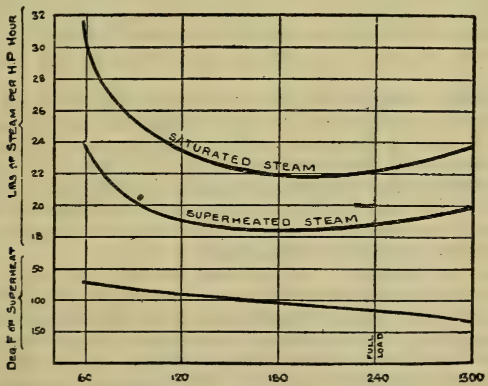


Fig. 31. Curve of steam consumption for 240 h.p. Ideal Corliss Engine. (Amount of superheat varies from 75° F. at ¼ load to 133° F. at 1¼ load.)

must be added the cost of upkeep, interest and amortization for The number of high class workmen was doubled, while the number of unskilled laborers was reduced to a proportion of 2.5 to 1. The wages paid decreased to 1.45 cts. per ton of steam to which

chain grates and conveyer, amounting to 0.85 ct., so that the total cost was reduced to 2.3 cts., which is almost ⅔ of the original amount. This saving was effected by employing automatic machinery and high class labor in the place of unskilled labor.

Saving in Steam Due to Superheat. The following data were obtained from the Power Specialty Co. Results of tests by Belliss & Morcom, Ltd., of Birmingham, on one of their high-speed triple-expansion engines, are shown in Fig. 30.

A 330 h.p. Lenz cross compound engine having 37.5 in. and 63 in. diam. cylinders and 55 in. stroke, at the Municipal Electricity Works of Charlottenburg, Germany, with 192 lbs. gauge pressure, 26 in. vacuum, 107 rev. per min., gave the following steam consumption per indicated h.p.

STEAM CONSUMPTION PER I.H.P., LBS.

Load.	¼	½	¾	1/1	5/4
Superheat 185 deg. F.	11.1	10.1	9.5	9.2	9.7
Superheat 275 deg. F.	10.6	9.7	9.0	8.8	9.2

Saving due to superheat on a 240 h.p. Ideal Corliss Engine is shown in Fig. 31.

The saving in steam consumption by superheating 100 deg. F. is from 18% to 20% for simple engines to 10% for steam turbines.

Superheaters, Advantages. Efficiencies and Costs. Fig. 32, showing the heat necessary to superheat steam above saturated steam, also the heat required to dry steam with from 1 to 5% of moisture was prepared by the Power Specialty Co. of Dansville, N. Y., who have kindly furnished us with a copy through the courtesy of R. H. Wyld.

Advantages. With a dry gas the friction in pipe lines is much less than with wet steam, or even with saturated steam (which is a vapor that is becoming wetter each moment). Therefore a superheated steam line can be smaller in diam. for the same efficiency than when wet steam is employed. A corollary to this is that with the same boiler pressure the installation of a superheater will not only reduce the fuel consumption but will increase the end steam pressure on a long line.

Increase in Capacity. The average increase in boiler capacity that can be added by installing superheaters is about 15%.

Superheat in Reciprocating Engines. In the average triple expansion engine, with 100 deg. of superheat, 12% of steam will be saved by superheaters in average compounds 14 to 15%, and the average simple engines, 18 to 20%. With small direct acting steam pumps and auxiliaries, the saving may be as high as 25 to 40%.

Superheat in Turbines. 10 degs. of superheat in a steam turbine are good for about 1% saving in steam. This will hold true up to 100 degs. and possibly to 150 degs., above which there is a tendency to fall off.

The early stages of superheat are of particular value on account of the collateral saving of moisture. 1% of moisture in steam is believed to decrease turbine economy by about 2%.

All turbine guarantees are based on dry steam, which is a practical rarity.

Cost of Installation. For 100 degs. of superheat, on ordinary plants working at 150 lbs. per sq. in. pressure, the cost of superheaters delivered and installed averages about $3 per h.p., maximum $3.50, minimum $2.50. (Also see page 592.)

Time to Install. On ordinary boilers the equipment will be out of service a minimum of about 4 days while the superheaters are being installed.

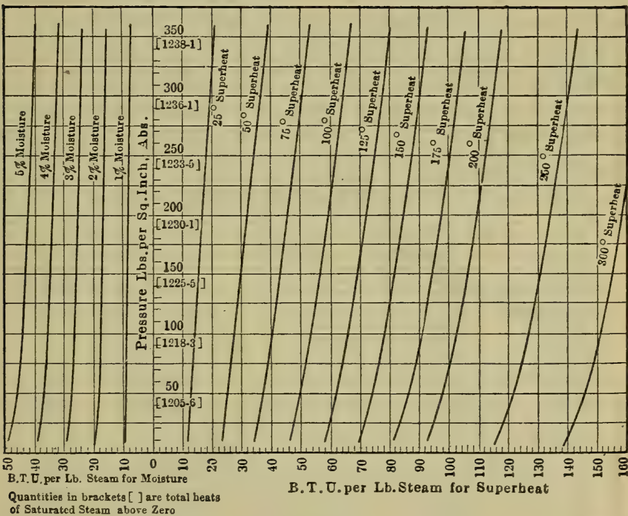


Fig. 32. Diagram of the amount of heat necessary to superheat steam above saturated steam.

Conditions Governing the Use of Super-Heat. O. S. Lyford, Jr., and R. W. Stovel, in the Electric Journal, April, 1912, state that the over-all efficiency of a large boiler plant will be increased from 5 to 7% by the use of superheat ranging from 100 to 150 degs. F., and that, generally speaking, superheat is economical even with coal as low as $1.50 per ton.

Since the general effect of superheaters is to raise the average temperature of the steam and its corresponding pressure, thus giving greater velocity to the supply pipes, these latter need not be so large as where no superheater is used.

Increasing the Economy and Capacity of Steam Boilers by the Use of Forced Draft. The following data were given by Henry Kreisinger and Walter T. Ray in U. S. Geological Survey Bulletin No. 412.

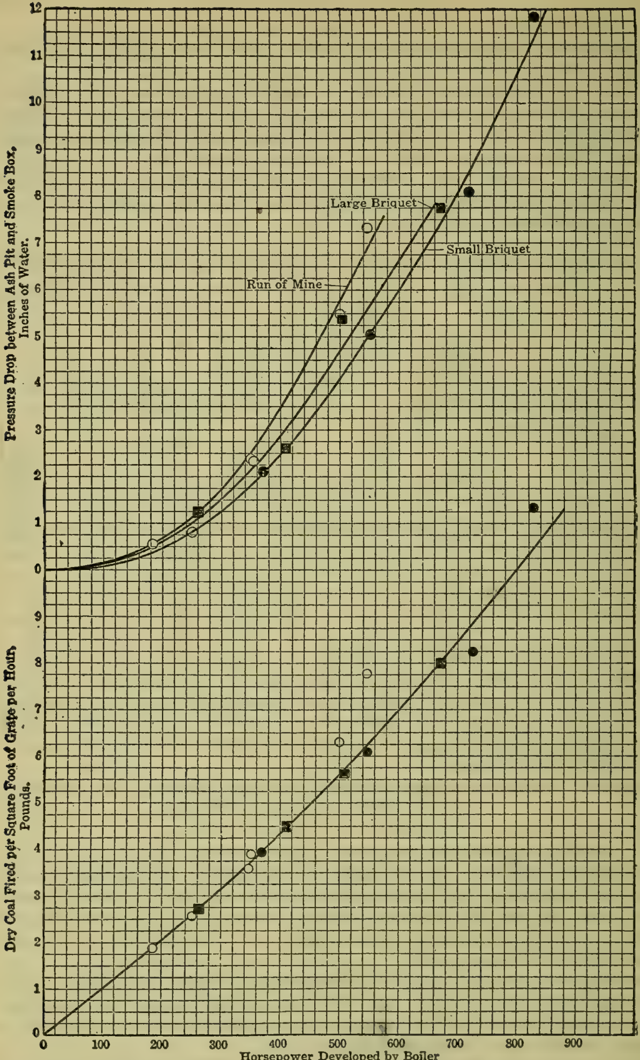


Fig. 33. Data of tests of locomotive boiler. (Showing how the "square" law of the pressure agrees with actual results.)

The total pressure drop between ash pan and smoke box for different outputs is plotted from 14 tests, 4 of which were made with small round briquets, 4 with large square briquets and 6 with run-of-mine coal, which contained a large quantity of slack that was carried out of the furnace before it had time to burn, thus resulting in a loss of the potential heat of the fine coal. Hence, briquet curves are more reliable than that of the coal. Note on the small briquet curve that when the total pressure drop was 2 ins. of water, the boiler developed 365 h.p. to double which, the pressure drop must be increased to about 8.5 ins. of water. Likewise with a pressure drop of 3 ins. and 435 h.p., the capacity curve follows the "square" law. Further proof of this law is obtained in the U. S. Geological Survey Bulletin No. 367.

The product of the pressure drop and the volume of gases displaced is equal, or proportional to the work done by the fan, and since the former increases according to the "square law" and the second directly as the capacity of the boiler, the work of the fan increases about as the cube of the capacity.

Table V gives the fan work required for the multiple capacities and other related items calculated from the above mentioned "cube" law.

TABLE V

Capacity of boiler battery, % of rating.	Boiler h.p. developed by boiler battery.	Relative work of fan.	Steam consumed by fan engine, expressed in boiler h.p.	Steam consumed by fan engine in % of total steam generated.
100	1,000	1	10	1
200	2,000	8	80	4
300	3,000	27	270	9
400	4,000	64	640	16
500	5,000	125	1,250	25
600	6,000	216	2,160	36
700	7,000	340	3,400	49
800	8,000	512	5,120	64
900	9,000	819	8,190	81
1,000	10,000	1,000	10,000	100

Note that if the steam consumption of the fan were 2% when the boilers are run at their normal rate their capacity could not be raised more than 7 times the normal rating, on which basis it would seem that it is not practicable to increase the rate of working of ordinary steam boilers more than three-fold, nor that of boilers of approved efficiency more than four-fold. The writers of the paper state that the mechanical efficiencies of most fans used at present for draft purposes range from 10 to 50%, and with many closer to the lower than the higher limits.

Fig. 34 gives the data and results of a series of 21 tests made of a Normand water-tube boiler on the U. S. Torpedo Boat *Biddle,*

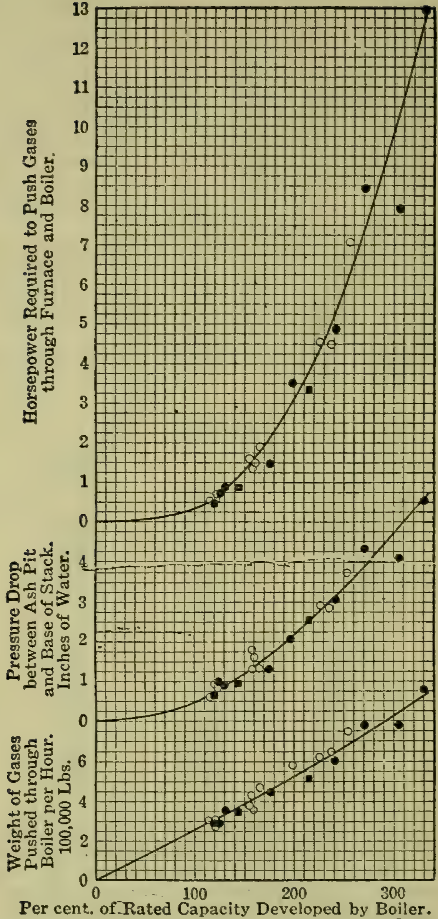


Fig. 34. Data of tests of Torpedo Boat Boiler. (Giving power required to push the gases through furnace and boiler.)

made with run-of-mine coal, (represented in the figure by hollow circles), small briquets, (represented by solid circles), and large briquets, (represented by solid squares). The boiler had 2770 sq. ft. of heating surface, corresponding to 277 boiler h.p. on the basis of a stationary boiler, further details of the test being contained in U. S. Geological Bulletin No. 403. The weight of gases passed through the boiler and furnace per hour was computed from the weight of coal burned and the flue-gas analysis. The curve shows that the capacity of the boiler increases nearly but not quite as fast as the weight of gases passing through the furnace and boiler.

The middle curve shows that the total pressure drop increases very nearly as the square of the capacity.

In the upper curve the power has been computed from the total pressure drops and the volume of air displaced, the latter being

TABLE VI. RELATION BETWEEN BOILER OUTPUT AND STEAM CONSUMPTION OF DRIVEN FAN

Capacity of boiler battery, % of normal rating.	Boiler h.p. developed by boiler	Power required to run the fan, mechanical h.p.	Steam accountable to fan per hour, lbs.	Steam accountable to fan, % of total steam generated.
100	1,000	2.25	34	0.125
200	2,000	18.00	272	0.500
300	3,000	60.75	918	1.125
400	4,000	144.00	2,056	2.00
500	5,000	281.25	4,250	3.125
600	6,000	485.00	7,344	4.500
700	7,000	771.75	11,662	6.125
800	8,000	1,156.00	17.408	8.000
900	9,000	1,640.00	24,786	10.125
1,000	10,000	2,250.00	34,000	12.500

figured from the data of the lowest curve. It shows that the power required to move the air increases very nearly as the cube of the capacity. The pressure difference was obtained by forcing air into the fire room and maintaining a pressure therein. The wheel of the blower supplying the air was 5 ft. in diam. and was directly in the fire room, being protected by a wire screen. The blower had no casing. There were no ducts and no leakage losses.

The blades of the blower wheel were curved in the direction opposite to that of the rotation, which together with the omission of casing made the blower highly efficient. The engine driving the fan was capable of developing about 20 to 25 h.p., operated by steam, with maximum speed of 1000 revs. per min.

When the boiler was working at capacity of 330% it required about 13 h.p. to push the gases through the boiler, at which rate

of working the power delivered to the shaft of the blower was probably less than 20 h.p. or 2% of the energy which can be developed from the total steam made in the boiler.

The reason for the low efficiency of the existing mechanical draft appliances is that the power actually needed to move the gases through the boiler is so low that it would not pay to save part of it at the price of increased first cost for draft apparatus. It would hardly be good economy to spend several hundred dollars for more efficient fans and motors, and the construction of large air ducts to save perhaps 1% on the coal bill; but in the future if boilers are to be worked 3 or 4 times as hard as they are at present the power required to push the gases through the boiler will increase to a considerable amount so that it will pay to install draft apparatus of high efficiency. By a proper design of the boiler plant, the first cost of the draft installation can be greatly reduced, and it may be possible to shorten the length of large, expensive air ducts by placing independent fans for each battery of boilers either above or under the boilers which they operate.

It seems entirely practicable to increase the rate of working steam boilers to at least 3 and possibly 5 or 6 times the present rate. The cost of installing highly efficient draft apparatus of high pressure and high capacity will be small compared with the saving of the cost of installing extra boilers.

A collateral advantage from the use of high pressure draft apparatus necessarily greatly increases the speed of the gases in the flues and all other gas passages, and consequently it will be very much more difficult for any soot or ash to collect on the heating plates or in the flues or tubes and reduce the efficiency.

In the furnace excessively high gas velocities are not desirable. Since the burning of large quantities of coal with small grate areas and combustion spaces would necessarily involve a rapid flow of gas through the fuel bed which may carry the small pieces of coal out of the furnace, and the combustible gases distilled from the fuel bed may pass through the useful combustion space before they are burned.

The velocity of the gases through the fuel can be reduced by increasing the grate area which is inversely proportional to the velocity of the gases. In most of the present boiler installations there is enough space under the boiler for twice the existing grate area.

The velocity of the gases through the combustion space can be reduced by increasing the space, which can, perhaps, be done by raising the boiler itself, and the combustion in many cases can be improved by using proper mechanical stokers operated on the principle of slowly heating the fresh fuel.

It is thus apparent that by doubling the grate area for instance, and doubling the present velocity of gases through the furnace, about 4 times the amount of coal could be burned, resulting in 4 times the weight of hot gases. By doubling or tripling the present effective combustion space and by the use of proper mechanical

stokers the combustion of the gases would be fairly complete before they would enter the boiler proper. Hence it appears to be possible to increase the ordinary steam-generating apparatus 3 or 4 times without having the steam part of it take any more floor space than it does for the present "normal" rate of working.

Reduction in Coal Costs by the Use of a Balanced Draft System. Walter L. Watson, in Engineering and Contracting, July 1, 1908, has described the following experience in the proceedings of the American Water Works Association in a plant consisting of 1-100-h.p. Vulcan Iron Works horizontal tubular boiler, operating prior to the installation of a special system of draft, at about 125 h.p., and using No. 1 buckwheat coal, at $2.30 per gross ton delivered, burning it with chimney draft, carefully regulating the damper by hand. This station was pumping about 1,500,000 gals. per 24 hrs. against a head of 342 ft., costing for fuel about $14.10 per million gals. pumped.

As against No. 1 buckwheat coal with natural draft evaporation tests were made with No. 3 buckwheat or barley coal with the balanced draft, with the result that the coal cost per million gals. pumped was reduced from $14.10 to $8.44, which saving has since been maintained.

The equipment consists of the following parts: First, a small turbine blower set directly against the ash pit wall, through which an opening is made to admit the air to the ash pit. The turbine exhausts into the ash pit. Its speed is automatically regulated by a special type of regulating valve.

A diaphragm damper controller is used, connected in such a manner to the blower, that the same variation of steam pressure that changes the speed of the blower, simultaneously changes the position of the damper.

The blower and damper are so adjusted, relatively one to the other, that there is at all times practically atmospheric pressure in the furnace chamber.

For each and every change in the speed of the blower, the damper assumes a different position within the limits of its travel. The air supply to the furnace and the exhaust of the gases from the furnace thus have a constant relation one to the other and the draft is at all times "balanced" against the atmosphere; hence the name "Balanced Draft."

The average steam consumption of the turbine is approximately 2% of the steam generated.

Increase in Capacity of Boilers Effected by an Increase in Grate Area without Increasing the Heating Surface. Walter S. Finlay, Jr., presented a paper on this subject at the meeting of the A. I. E. E. on December 13, 1907, from which we have abstracted the following.

Increase in capacity while the heating surface remains constant is accompanied by a loss in the economy of evaporation due to the increased temperature of the escaping gases. This loss varies from almost nothing to perhaps 15% in fuel economy for an increase

of 100% in boiler capacity. Under the theory that combustion, distribution and transfer of heat could be much improved under new conditions with careful attention to details of design, a change was made in the plans of 18 of the boiler furnaces in the Fifty-ninth Street plant of the Interborough Rapid Transit Co. of New York City and a second stoker was installed. This enabled the plant to operate within the range of the original single-stoker boiler, together with the higher range of the double stoker. The second stoker installed has an area of 80% of the original one, local conditions preventing an installation of a larger size; the second, or lower stoker, being constructed within a so-called "Dutch oven." Tests made after the installation indicated that, in this case, double-stoker operation covers the entire range of single-stoker operation and adds an increase in capacity proportionate to its larger grate surface, with no appreciable loss in economy, and an increase of 71% in capacity was accomplished with no loss in economy.

Using the above results as a basis, Mr. Finlay considers the effect of such a change upon a plant as a whole and derives the following figures assuming a plant with a first cost of $125 per kw., equipment including turbo-generators and boiler stokers, with a ratio of 60 to 1. Following are the derived results:

		%
Total cost per kw.	$125.00	100
Building	43.75	35
Boilers	6.875	5.5
Grates	1.75	1.4
Piping	5.625	4.5
Coal-handling apparatus per kw.	2.30	1.84
Balance of equipment	64.70	....

In figuring the expense of operating this plant the fixed charges were taken at 12%, including interest 5%, depreciation 6%, taxes and insurance 1%. The effect of a change, as outlined, on the different items making up the plant cost, is then considered as follows:

Piping: In the assumed case the cost of steam piping between boilers and manifolds, plus boiler feed piping and boiler blow-off piping alone has been considered. With any change in the number of boilers, capacity remaining constant, the cost of piping will vary in the same ratio multiplied by a factor which is due to the change in size of pipe.

Coal Handling Apparatus: Fixed plant capacity would seem to demand fixed cost of this item, but the proportionate value of the conveying apparatus is so great that any change affecting the length of carry will raise or lower the total cost of the system although not in direct ratio to such a change.

Change of Ratio: Assume that it is decided to cut in half the ratio of heating surface to grate surface by using double grates or stokers under boilers of the same rating, with unchanged plant output. The revised costs would then be as follows:

	Per kw.
Building (reduced 40%)	$26.25
Boilers (reduced 50%)	3.438
Stokers (remain same)	1.75
Piping (reduced 40%)	3.735
Coal-handling apparatus (reduced 15%)	1.955
Balance (remain same)	64.70
	$101.468

Thus the plant first cost and fixed charges would each be reduced 19.6%. From figures on this plant, furnished by Mr. H. G. Stott, Mr. Finlay estimates that the change to double grate operation would decrease maintenance and fixed charges by 25%.

The summary of the above figures would indicate the following: First cost, 19.6% saving; total plant charges varying from a saving of 5.64% at 100% load factor, to 7.54% at 50% factor, to 9.65% at 4.16% factor (365 hours per year).

Mr. Finlay also presented a set of figures on a plant cost of $150 per kw., for which he estimated a reduction in first cost and fixed charges of 20.8%.

The summary of the figures in the case of the $150 plant follows: First cost, 20.8% saving; total plant charges vary from 7.06% saving at 100% load-factor, to 9.26% at 50% factor to 11.51% at 4.16% factor.

Annual Saving from the Use of Soft Water in 1,000 h.p. Boiler Plant. From a press bulletin of the U. S. Geological Survey we have taken Tables VII and VIII.

TABLE VII. COMPARATIVE EXTRA COST WITH USE OF HARD WATER

Average coal consumption for 1,000 h.p. boiler, 48 tons a day, 48 tons of coal at $1.50 is $72. Estimated saving in fuel on this water due to use of treated water is 5%. Five % of $72 is $3.60 per day, or, for 300 working days	$1,080
Cleaning boiler, at $8 per week	416
Repairs for tubes, etc.	200
Boiler compounds	250
Coal for raising steam after cleaning, 104 tons at $1.50	156
7.5% depreciation on boiler plant costing $15,000	1,125
Total	$3,227

TABLE VIII. COMPARATIVE EXTRA COST WITH USE OF SOFTENED WATER

10% interest and depreciation on softening plant costing $3,500	$350
Boiler repairs	50
Chemicals at 1 ct. per 1,000 gals.	300
Coal for raising steam after cleaning, 16 tons at $1.50	24
5% depreciation on boiler plant costing $15,000	750
Total	$1,474

The total saving is, therefore $1,753, which is practically half the cost of installing a softening plant.

Saving Derived from Water Softening Plant. G. H. Gibson, Power, September 14, 1909. An installation of 300 h.p., consisting of 4 Franklin and 2 Sterling water-tube boilers, taking the water from a creek, the analysis of which water shows the following substances by solution.

	Grains per gallon.
Silica	0.03
Calcium carbonate	8.83
Magnesium "	0.33
Calcium sulphate	9.66
Magnesium "	4.79
Sodium chloride	2.54
F E 203 & A L 302	0.02
Total	26.20

These boilers evaporate about 100,000 gals. of water per day, which would precipitate within the boiler 380 lbs. of scale, or over 70 tons per yr., and due to the large proportion of sulphate, this scale would be quite hard. In fact before the installation of the water softening plant, a force of 3 men was maintained to clean the boilers and replace tubes, failures of which were almost a daily occurrence.

After the installation of a hot process system for softening the water, consisting in effect of an open feed water heater, suitably equipped and modified to provide the necessary time and space for the settlement and filtration of the precipitate, resulting from the effects of heat upon carbonate and from the action of soda ash upon sulphate and chloride, it was found that only 1 man was required for cleaning the boilers which was accomplished with a hose, and that there were but few fractured or leaky tubes.

It was also found that whereas the work of the plant had somewhat increased, the consumption of coal had been reduced from 42 to 32 tons per day. On the basis of coal at $2.50 per ton, and figuring that 1 new boiler tube per day was formerly required at $2.00 per tube, the saving from the installation of the softening system was about as follows:

3,600 tons of coal	$9,000
Wages of 2 men for 1 year	900
300 new tubes per year	1,500
Total	$11,400

The treatment of the water required 200 lbs. of soda ash per day, costing $600 per year. The labor required for operation was 2.5 hrs. time of 3 men every 2 weeks, or about $36 per yr., making a total cost of operation of the system of $636, which makes the net saving from the operation of the plant, $10,764, or about 4 times what the system cost.

This does not take into account the longer life of the boilers because of the protection from corrosion, scale and cleaning tools, nor the increased steaming capacity through always feeding the boilers with hot water.

Results from Operation of Water-Treating Plant. The following article, by H. G. D. Nutting, is from Electrical World, December 4, 1915. Considerable trouble has been experienced by the Mineral Point (Wis.) Public Service Company in securing satisfactory boiler-feed water. The creek water and well water of the vicinity is hard, and in spite of the use of boiler compound a hard scale about .1875 ins. thick collects on the boiler tubes and shells in a run of 3 weeks. The effect of this scale on boiler operation and maintenance cost suggested an investigation of methods of water treatment which resulted in the installation of the apparatus shown in Fig. 35.

The water-treating plant consists of 2 elements — a 30,000-gal. steel settling tank and a chemical proportioning and feeding device. The settling tank is about 13.5 ft. in diam. by 25 ft. in height.

The operation of the softener is automatic and requires operating attention only to provide daily a chemical mixture of lime and soda ash. The water is tested each day, the chemical orifice cleaned out, and the sludge blown off in addition.

The cycle of operation of the softener is as follows: When the pure-water level has dropped to a point (by feeding to the feed pumps) where the controlling float 5 causes the valve 4 in the raw-water pipe to open, the raw water discharges into the waterwheel buckets 2, causing the paddles 6 to stir the chemical solution in the upper tank and also operate the chain buckets, thus delivering the chemical solution into the constant-level cup 7. The chemical solution then flows through the fixed orifice in 7, through the pipe 11, to the down-take 12 of the settling tank. The raw water is exhausted from the waterwheel into the settling-tank down-take pipe 12, where it mixes with the chemical solution and is stirred by paddles arranged on a vertical shaft, actuated by the waterwheel through the bevel gears 13. As the water level rises in the settling tank, the float 5 rises and at a predetermined point shuts off the raw-water valve 4. This cycle of operation requires about 10 mins., during which time treated water is also being drawn from the softener to the heater through the outlet 15. The softener remains idle for about 10 mins. or longer, depending upon the water required, and then starts again.

The time and number of cycles of operation are recorded by an electrical curve-drawing voltmeter contacted by the main-control float rod 5, so that, by means of a calibrated orifice, operating under a constant head controlled by a float, the amount of water softened is determined. By adding the amount of steam condensed in the heater, which can be accurately calculated from the record of inlet and outlet temperatures at the heater and the amount of water delivered to the heater from the softener, a record of daily water evaporated in the boilers is obtained. This quantity is corrected for the amount of water blown out of the softener with sludge, as determined by calibration of the sludge blow-off valve.

To provide the hottest water possible to the softener and secure the best economy of heat distribution throughout the plant, the

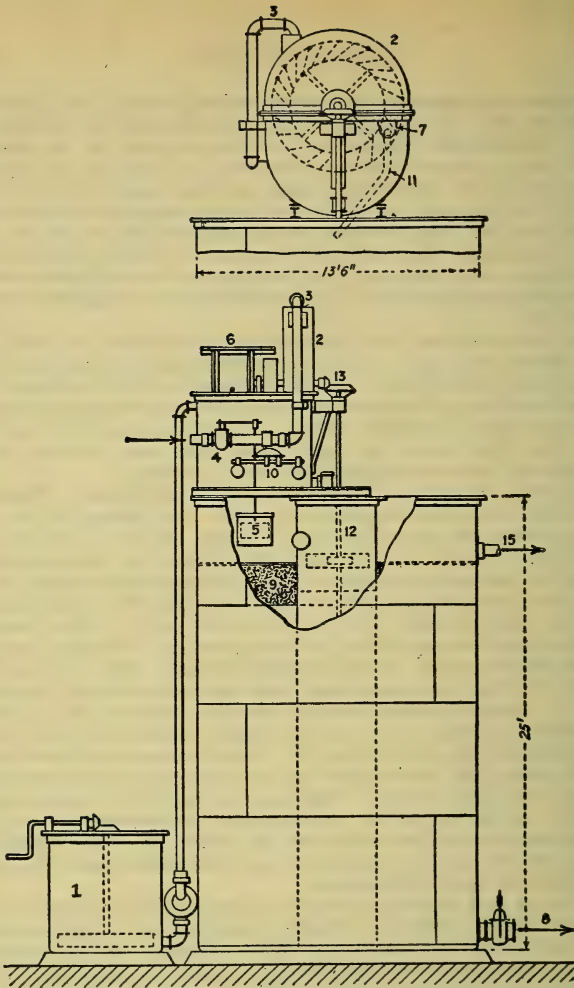


Fig. 35. Settling tank, chemical proportioning and feeding device of water-treating plant.

The mixing tank shown at 1 is installed on the ground level, provided with a hand-operated stirring paddle and a steam siphon for lifting the chemical solution to the chemical tank on top of the settling tank. The waterwheel at 2 is operated by the raw water discharged into the settling tank through the pipe 3. A raw-water control valve at 4, operated by float 5, is controlled by the water level of the treated water. The paddle wheel 6 used to stir the chemical solution in the upper chemical tank is operated by the waterwheel. The constant level cup 7 contains an orifice for feeding the chemical solution in the correct proportion to the raw water, and a bucket chain (not shown), for keeping the constant level cup full, is operated from the waterwheel. A sludge blow-off pipe is shown at 8 and a filter at 9. A raw-water-measuring device consisting of an orifice and a constant head control is indicated at 10.

water to be treated is taken from the discharge side of the Westinghouse Le Blanc condensers without additional pumping, the discharge head being sufficient to operate the softener. This water has a temperature of from 90 degs. F. to 120 degs. F., depending upon the load and weather conditions. The "make-up" water, which is practically equivalent to the amount used by the turbines not including the auxiliaries, and which is comparatively cold water, is fed to the condenser injection pipe. In this way the hot water is delivered at its most advantageous point (direct to the softener) and the cold water at its most advantageous point (the condenser).

The amount of chemicals required per day on the average is 35 lbs. of soda ash and 125 lbs. of lime. This amount is sufficient to treat 65,000 gals. of creek water per day, which shows by test not more than 5 grains of scale-forming material per gal. after treatment. The cost per 1000 gals. of water is 1.63 cts. The daily cost of softening chemicals is about $1, whereas before the treating plant was installed the cost per day for compound was $2.40 and the load was less than at present. The chemicals are purchased by the car-load at low prices, the soda ash costing 1 ct. per lb. and the lime 0.5 ct. per lb.

All chemical charges to the ground mixing tank are weighed on platform scales and the tank is calibrated, so that by means of a measuring stick the strength of the solution can be determined. The mixing is done by an ordinary laborer under the direction of the chief engineer. After mixing, the charge is stirred, and while being stirred it is elevated to the upper tank by means of a Crane steam siphon, in about 10 mins., with a small expenditure of steam.

Each day the treated water is tested by the chief engineer, by means of a testing cabinet furnished by the manufacturer of the softener. This would seem to be a formidable venture, in view of the time and knowledge required to make a laboratory analysis of water. As a matter of fact, it is quite as simple as making a CO_2 analysis, and requires about 15 mins. to perform. The test is conducted to determine (1) hardness, (2) causticity, (3) alkalinity.

The hardness test is made by placing 100 cu. cm. of the water to be tested in a bottle and adding a "standard soap solution" from a measuring burette. The bottle is then shaken and the soap solution added in small quantities until the lather will hold together firmly for five minutes. A little practice in this test will produce duplicate results within a reasonable practical error.

Causticity is determined by adding phenol to 100 cu. cm. of the water to be tested in a porcelain dish, the phenol serving as an indicator. An acid solution is then added from the measuring burette until the solution again becomes clear. The number of cu. cms. of acid-testing solution added gives the measure of causticity.

The alkalinity test is made by adding methyl orange to the same water tested for causticity. The methyl orange gives this water a straw color. The acid-testing solution is again added from the

burette until the indicator turns pink. The amount of acid-testing solution added gives the test for alkalinity.

The relations between alkalinity and causticity tests are important in showing correct reatment. The test indicating proper treatment should be about as follows: Hardness, 6; causticity, 4; alkalinity, 7.

TABLE IX. ANALYSIS OF RAW CREEK WATER USED BY MINERAL POINT PUBLIC SERVICE COMPANY

Content	Grains per U. S. gallon	Content	Grains per U. S. gallon
Silicia	0.04	Sodium chloride	2.97
Iron and aluminum oxides	0.14	Total solids	29.96
Calcium carbonate	11.03	Incrusting solids	22.26
Magnesium carbonate	1.32	Organic and volatile matter	4.73
Magnesium sulphate	8.93	Alkalinity	12.60
Magnesium chloride	0.80	Hardness	22.00

TABLE X. OPERATING CONDITIONS BEFORE AND AFTER TREATING BOILER-FEED WATER

Item. Conditions before treating water.

1. Comparatively low economy of evaporation.
2. Lost, on an average, thirteen boiler tubes per month, costing about $10 each, including cutting out old tubes and replacing new ones.
3. Rapid depreciation and high maintenance cost of brickwork due to extinguishing and starting of furnace fires.
4. Loss of service of boilers and shut-down due to loss of steam when tubes blew out.
5. Danger from explosion.
6. Loss of coal in burning down and building up fires and loss of heat in water.
7. Continuously calking leaks in tubes and shells.
8. Compound deposits on feed-pipe valves.
9. Required to clean heater weekly and feed cold water to boilers while doing so. Heater never could be thoroughly cleaned.
10. Expense of frequent turbining of boilers (every three or four weeks) with consequent expense for hand-hole and manhole gaskets, labor, power for turbine, etc.
11. Turbo-generator sealing glands stopped up with scale, requiring turbine to be taken apart and cleaned, with consequent loss of service and with considerable expense.
12. Numerous other troublesome conditions of a minor character. In some cases even loss of vacuum was caused by scale.

Item. Results secured by treatment.

1. The coal bill has been reduced by 18% of its former amount, based on the same load. The coal bill for July, the second month of use of the water softener, was $514 less than for May, when the softener was not in use — *i.e.*, based on the same output.
2. No boiler tubes have been lost since the softener began to effect results, in spite of the fact that the boilers have been above rating most of the time.
3. The load has been carried on 1 500-hp. and 1 250-hp. boiler, whereas previously 1 500-hp. and 2 250-hp. boilers were required. Incidentally, the load has increased while the horsepower of the boilers in service has decreased.
4. Scale has practically disappeared, leaving the black iron.
5. Maintenance and depreciation of brickwork have been diminished.

Item. Results secured by treatment.

6. Additional coal is saved, owing to lack of necessity of burning down and rebuilding fires and reheating water.
7. Danger of blow-out tubes eliminated.
8. Leaks stopped. (Immediately after starting the softener, several leaks opened up in the tubes and shells of one boiler. This was caused by a fireman permitting low water, although the elimination of scale from the tubes and shells probably aggravated the conditions. After calking and rolling, no leaks have reappeared.)
9. No deposits on or eating out of valves.
10. Heater now washed out every 2 or 3 weeks (previously it was cleaned weekly). Very little deposit found. What little is found probably caused by overtreating the water slightly.
11. No turbining required. It is anticipated that once a year will be sufficient.
12. Turbine glands remain clear. No cleaning required.
13. Less loss from blowing down.
14. No loss of vacuum from scale on atmospheric relief valves and other trouble caused by scale.

The results in Table X have been shown by the use of the water softener two months and indicate that the external treatment of feed water at this plant returns a very handsome profit on the investment required. The apparatus cost about $3,000 installed.

This installation, in addition to furnishing treated water for the boilers of the central station, provides soft water for the Mineral Point & Northern Railroad Company for use in its locomotives. It is reported that a saving in coal similar to that of the operating company has been made, and, further, that fewer leaks are encountered. One of the engineers has stated that previous to using soft water he did not get out of the yards in the morning before his flues started leaking. Since using soft water he has had no more leaks. This also results in a saving of water, as a large amount leaked out on each trip. It is anticipated by the management of the railroad, based on the saving so far, that the saving in maintenance cost will be at least as great as the saving in fuel. The Chicago, Milwaukee & St. Paul Railway Company has also contracted for a supply of this water and is now using it.

The Mineral Point Public Service Company serves a group of cities in southwestern Wisconsin, as well as several zinc mines, with light and power. The station equipment consists of 4 250-hp. and 2 500-hp. Heine boilers, 1 1200-kw. Allis-Chalmers turbine, 1 1200-kw. Westinghouse turbine, and 1 275-kw. directly connected Nordberg engine-generator set. The condensing water is cooled by a Stocker cooling tower and by a cooling pond recently constructed. Make-up water is pumped sometimes from a creek running past the power house and sometimes from wells.

The softener is made by the Northern Water Softener Company of Madison, Wis.

Costs of Cooling Ponds. From Electrical World, Oct. 9, 1915. Tables XI and XII give data on the operation and cost of constructing cooling ponds equipped with spray nozzles for cooling the circulating water of condensers used with steam engines and turbines. In order to make a proper comparison of the costs of cooling arrangements for prime movers varying in rating from 500 kws. to

TABLE XI. OPERATING DATA FOR SPRAY COOLING SYSTEMS USED WITH PLANTS OF VARIOUS RATINGS

Location of plant	Mass.	N. J.	N. J.	N. J.	Md.	Pa.	S. C.	Tex.	Tex.
Rating of engines or turbines, kws.	500	550	1,200	125		14,250	2,600	1,500	300
Type of condenser	Surface	Jet	Surface	....		Jet	Jet	Surface	Jet
Operating vacuum	28.5	27.5	28.0	28.0		29.0	25.0	28.5	27.0
Gallons water per minute to condenser	1,610	2,000	3,200	150	850	10,000	4,000	3,700	866
Rating of spray system, gallons per minute	2,880	2,000	8,000	660	1,600	7,920	4,500	3,840	800
Number of nozzles	72	50	200	20	40	132	75	96	20
Temperature of water leaving condenser, degs. F.	90	100	100	115	182	99	130	105	110
Temperature of water in cooling pond, degs. F.	75	88	90	89	100	82	100	96	94
Average air temperature during summer, degs. F.	71.3	72.5	72.5	72.5	77.3	71.8	77.8	80.5	83.0
Relative humidity during summer, degs. F.	70.0	84.0	84.0	84.0	70.0	68.0	69.0	76.0	51.0
Pond area, sq. ft.	9,240	2,500	14,000	4,800	3,500	360,000	40,000	10,000	2,000
Capacity of pond, thousand gals.	230	100	350	72	80	14,889	1,800	300	....
Number of times water is sprayed	1	1	1	1	2	1	1	1	1
Source of water supply	Well	Mine	Well	Well	Well	Well	River	River	Well
Cost of water per 1,000 gals., cts.	0.0	0.0	1.5	0.0	1.5	3.0	0.0	0.0	0.0
Pumping charge per hr. in kw.-hr.	10.0	40.0	40.0	10.0	22	250	60	....	10
Approximate cost of cooling system	$7,000	$8,000	$10,000	$1,000	$7,500	......	$4,000	$3,000	$1,800

2000 kws. it is necessary to assume a steam consumption that is fairly consistent with plant practice in each case. For the 500 kw. turbo-generator a steam consumption of 22 lbs. per kw.-hr., when operating at a 17.5 in. vacuum referred to a 30 in. barometer, is taken as an average water rate for summer weather in the Middle and Southern states, or a total steam consumption of 11,000 lbs. per hr. for the unit. In order to obtain the vacuum mentioned, it is necessary to have a ratio of circulating water to steam of 60 to 1, therefore 1320 gals. per min. of water will be circulated and sprayed at the cooling pond. This will require about 35 nozzles of a size to discharge approximately 40 gals. per min. at 7 lbs. pressure at the nozzle. The cost of such an equipment of nozzles, spray heads, spray arms, drip sprays and piping, including eccentric spray, tees, valves when required, suction-well wall piece and flange-by-bell elbow, is about $825 as shown in Table XII.

TABLE XII. COST OF CONSTRUCTING COOLING PONDS WITH SPRAY NOZZLE EQUIPMENT

Size of steam unit, kws.	500	1,000	2,000
Assumed steam consumption, lbs. per kw.-hr.	22	20	18
Total steam condensed per hr., lbs.	11,000	20,000	36,000
Circulating water required, 60 to 1 ratio, gals. per min.	1,320	2,400	4,320
Number of nozzles required	35	60	110
Cost of nozzles, equipment and piping complete	$825	$1,585	$2,310
Size of cooling pond required, ft.	50 by 128	90 by 90	112 by 120
Approximate cost concrete basin complete	$2,560	$3,240	$5,400
Approximate cost puddled clay basin complete	$1,280	$1,620	$2,700
Approximate cost concrete basin, equipment and piping complete	$3,385	$4,825	$7,710
Approximate cost puddled clay basin, equipment and piping complete	$2,105	$3,205	$5,010

The size of the pond required for a 500 kw. installation should be about 50 by 128 ft. with the sprays arranged in 7 groups of 5 nozzles each, connected to a pipe line down the center of the pond. If a concrete basin is required, it should have a 5 in. reinforced concrete bottom and side walls, the side walls having a slope of 2 to 1 to avoid the cost of forms In this case the pond should have a suitable suction well with double screens to prevent the nozzles from clogging and also piers carrying plates and rolls on which the piping can rest. The total construction cost for such a pond, including the excavation, will be about 40 cts. per sq. ft. under average conditions with no hazards, or a total of $2,560 for the concrete basin complete. This amount added to the cost of the special equipment and piping makes the total approximate cost for the 500 kw. installation $3,385.

If the conditions are such that a pond can be constructed with a 6-in. puddled clay bottom and the bank lined with puddled clay of the same thickness, the cost would be about 20 cts. per sq. ft., or

TABLE XIII. YEARLY COSTS OF STEAM POWER, 308 DAYS, 10 HOURS PER DAY, SIMPLE NON-CONDENSING

Type of engine	Engine and boiler combined.						
Horse power of engine	2	3	4	6	8	10	12
Total coal consumption in lb. per hp. hr.	13.	10.5	8.5	7.9	7.6	7.4	7.25
Cost of plant per hp.	$200.	$152.	$133.	$110.	$89.	$83.	$78.
Fixed charges on plant, 11%	44.	50.	58.20	71.50	78.20	91.50	102.
Cost of coal at $5 per long ton	180.	215.	235.	325.	420.	510.	600.
Attendance	99.	109.	116.	136.	154.	173.	184.
Oil, waste and supplies	13.20	14.30	15.40	17.60	20.	22.	23.80
Total yearly cost, coal at $5 per ton	336.	388.	424.	550.	672.	796.	910.
Total yearly cost, coal at $4 per ton	300.	345.	385.	495.	610.	720.	810.
Total yearly cost, coal at $3 per ton	265.	300.	340.	430.	530.	630.	710.
Yearly cost per hp., coal at $5 per ton	168.	130.	106.	92.	84.	79.6	76.
Yearly cost per hp., coal at $4 per ton	152.	116.	95.	81.	76.	72.	68.
Yearly cost per hp., coal at $3 per ton	132.	102.	83.	72.	66.	63.	59.

Type of engine	Engine and boiler independent.								
Horse power of engine	10	12	14	15	20	30	40	50	75
Total coal consumption in lb. per hp.-hr	7.4	7.25	7.0	6.5	6.0	5.5	4.75	4.5	4.0
Cost of plant per hp.	$210.	$194.	$182.	$174.	$153.	$126.	$107.	$96.	$79.
Fixed charges on plant, 11%	230.	255.	280.	285.	337.	415.	475.	525.	650.
Cost of coal at $5 per long ton	510.	600.	675.	690.	830.	1100.	1310.	1540.	2050
Attendance	173.	184.	194.	202.	230.	287.	338.	390.	520.
Oil, waste and supplies	22.	23.80	25.80	26.50	31.20	41.50	51.	61.50	86.
Total yearly cost, coal at $5 per ton	935.	1063.	1175.	1203.	1428.	1843.	2194.	2516.	3306.
Total yearly cost, coal at $4 per ton	840.	960.	1050.	1080.	1260.	1660.	1960.	2250.	3000.
Total yearly cost, coal at $3 per ton	740.	830.	920.	950.	1100.	1450.	1710.	1960.	2650.
Yearly cost per hp., coal at $5 per ton	93.50	88.	83.	80.	71.	60.	55.	50.	44.
Yearly cost per hp., coal at $4 per ton	84.	79.	74.	72.	64.	54.	49.	45.	39.
Yearly cost per hp., coal at $3 per ton	74.	68.	64.	62.	56.	47.	42.	39.	34.

TABLE XIV. YEARLY COSTS OF STEAM POWER, 308 DAYS, 10 HOURS PER DAY, SIMPLE CONDENSING

Horse power of engine	10	12	14	15	20	30	40	50	75	100
Total coal per hp. hour, lb.	7.	6.75	6.50	6.02	5.50	5.25	4.75	4.25	3.70	3.50
Cost of plant per hp.	$220.	$204.	$192.	$186.	$163.	$134.	$120.	$108.	$93.	$81.
Fixed charges on plant, 11%	242.	270.	295.	307.	360.	440.	530.	590.	765.	890.
Cost of coal at $5 per long ton	480.	560.	625.	670.	750.	1040.	1310.	1470.	1910.	2420.
Attendance	178.	190.	202.	210.	238.	297.	350.	405.	535.	670.
Oil, waste and supplies	22.80	24.80	26.70	27.60	32.50	43.	53.	64.	89.	114.
Total yearly cost, coal at $5 per ton	923.	1045.	1149.	1215.	1380.	1720.	2243.	2529.	3299.	4094.
Total yearly cost, coal at $4 per ton	830.	940.	1030.	1100.	1240.	1550.	2020.	2270.	2961.	3700.
Total yearly cost, coal at $3 per ton	730.	820.	900.	960.	1080.	1360.	1770.	2010.	2600.	3250.
Yearly cost per hp. coal at $5 per ton	92.30	87.	82.	80.	69.	57.	56.	51.	44.	41.
Yearly cost per hp. coal at $4 per ton	83.	78.	74.	72.	62.	51.	50.	46.	39.40	37.
Yearly cost per hp. coal at $3 per ton	73.	68.	65.	63.	54.	44.50	43.50	40.	34.50	32.50

1 man attends engines, fires boiler and is supposed to do other work besides. On the 10-hp. plant ¼ of his time is charged to attendance, and ¾ of his time on the 100-hp. plant.

TABLE XV. YEARLY COSTS OF STEAM POWER, 308 DAYS, 10 HOURS PER DAY, COMPOUND CONDENSING

Horse power of engine	100	200	300	400	500	600
Total coal per hp. per hr., lb.	2.75	2.45	2.40	2.35	2.30	2.25
Cost of plant per hp.	$105.60	$93.30	$86.20	$76.20	$71.20	$67.30
Fixed charges on plant, 11%	1160.	2060.	2850.	3350.	3920.	4451.
Cost of coal at $5 per long ton	1910.	3370.	5100.	6700.	8380.	9650.
Attendance	880.	1220.	1220.	1760.	1930.	2100.
Oil, waste and supplies	143.	205.	240.	285.	315.	350.
Total yearly cost, coal at $5 per ton	4198.	6948.	9496.	12171.	14596.	16618.
Total yearly cost, coal at $4 per ton	3780.	6200.	8550.	11000.	13200.	15700.
Total yearly cost, coal at $3 per ton	3300.	5400.	7500.	9700.	11500.	13200.
Yearly cost per hp., coal at $5 per ton	42.20	35.10	31.50	30.50	29.20	27.70
Yearly cost per hp., coal at $4 per ton	37.80	31.50	28.40	27.	26.10	24.90
Yearly cost per hp., coal at $3 per ton	33.20	27.70	25.	23.80	23.	21.90
Number of men	1	2	2	3	3	3

Horse power of engine	700	800	900	1000	1500	2000
Total coal per hp. per hr., lb.	2.20	2.15	2.10	2.00	1.80	1.75
Cost of plant per hp.	$64.40	$62.20	$59.30	$55.70	$54.40	$53.20
Fixed charges on plant, 11%	4952.	5492.	5910.	6130.	9000.	11880.
Cost of coal at $5 per long ton	11000.	12500.	14300.	14500.	18600.	24200.
Attendance	2650.	2700.	2930.	3480.	4400.	5200.
Oil, waste and supplies	385.	420.	445.	470.	600.	685.
Total yearly cost, coal at $5 per ton	19050.	21674.	23644.	24595.	35100.	42018.
Total yearly cost, coal at $4 per ton	17200.	19500.	21200.	22200.	31500.	37800.
Total yearly cost, coal at $3 per ton	15200.	17100.	18500.	19500.	27500.	33000.
Yearly cost per hp., coal at $5 per ton	27.30	26.10	25.20	24.50	23.50	21.
Yearly cost per hp., coal at $4 per ton	24.60	23.50	22.60	22.	20.30	18.90
Yearly cost per hp., coal at $3 per ton	21.50	20.60	19.90	19.40	17.90	16.60
Number of men	4	4	4	5	6	7

$1,280 for the basin complete. Adding the cost of the special equipment and piping to this amount, the total cost of a pond of this character would be about $2,105.

On a similar basis for the 1000-kw. unit, assuming a steam consumption of 20 lbs. per kw.-hr., a ratio of circulating water to steam condensed of 60 to 1, and the same size of nozzles as before, spraying 2400 gals per min., 60 nozzles would be required. The cost of this equipment, with the necessary piping, fittings and

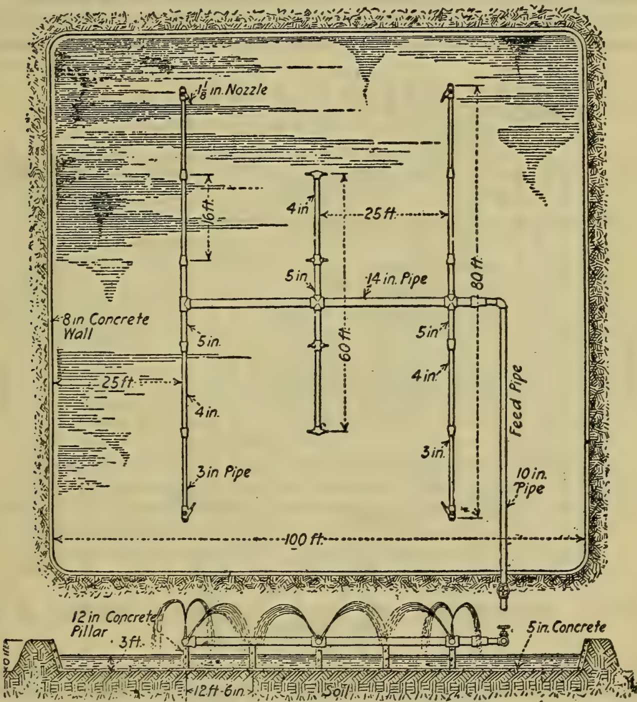


Fig. 36. Plan and elevation of cooling pond.

the like, would be around $1,585. This installation would require a pond 90 by 90 ft. or 65 by 125 ft., with an arrangement of 3 or 2 lines of pipe having 4 or 6 groups of sprays of 5 nozzles each per line. The cost of a concrete basin of these dimensions at 40 cts. per sq. ft. would be $3,240 and, including special equipment and piping, $4,825. For a pond with puddled clay bottom and sides the total cost would be $3,205. The costs for the 2000-kw. installa-

tion shown in Table XI are arrived at in the same manner, assuming a steam consumption of 18 lbs. per kw.-hr.

Cost of Making a Spray Cooling Pond. Power, April 13, 1915. Besides the pleasing appearance, the next important feature of this device is its durability. Being all iron and concrete (Fig. 36), there is practically no wear and nothing to require attention or get out of order, and there is no danger from wind storms. 15 lbs. pressure is all that is required to operate the spray. The loss by evaporation is about the same as in other spray cooling devices.

This cooler handles 1500 gals. per min., reducing the water to normal temperature. This is regulated by the pressure, and thereby

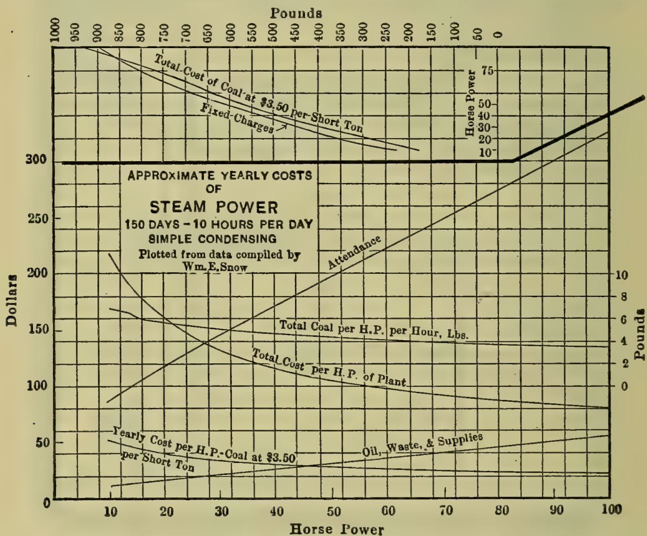


Fig. 37. Approximate yearly cost of steam power, 150 days at 10 hr. per day.

the height to which the spray rises; the humidity of the atmosphere is also a governing factor. The cost of the plant was as follows (estimated): Ground, $400; excavating (800 yds.), $250; concrete and labor, $1,250; iron pipes and nozzles, $550; total, $2,450

The cost of a cooling tower with fan to perform the same amount of work was estimated at $5,000. The brass nozzles are of special make and cost $500 for the 20 used. The bottom of the pond is lined with 5 ins. of concrete and the depth of water is about 3 ft. The concrete columns supporting the pipes are 12 ins. square in cross-section, and they are spaced 12 ft. 6 ins. apart on straight runs. The cooling pond has been in service about a year.

Cost of Steam Power. After Wm. E. Snow, Engineering Maga-

zine, May, 1908. These figures were compiled from a large amount of data obtained in many small power stations at various places, and are believed to be sufficiently accurate for any purpose of ordinary estimating. They are naturally general averages or approximations thereto.

Approximate Yearly Cost of Steam Power. The curves in Fig. 37 were plotted from data compiled by Wm. E. Snow and represent the approximate yearly costs of steam power, 150 days, 10 hrs. per day, for simple condensing engines.

The Cost of Steam Power for Small Engines. Tables XVI–XVIII are quoted from W. O. Webber's figures on the cost of one steam horse power per brake h.p. per year for simple engines as given in Engineering Magazine, July, 1908.

TABLE XVI. COST OF ONE STEAM H.P. PER BRAKE H.P. PER YEAR, SIMPLE ENGINES

Size of plant, h.p.	10	20	40	60	80
Cost of plant per h.p.	$230.	$200.	$190.	$180.	$175.
Fixed charges, 14%	32.20	28.	26.60	25.20	24.50
Coal per h.p. per hr.	15.	12.	10.	9.	8.
Cost of coal, $4.00 per ton	82.50	66.	55.	49.50	34.
Attendance 3,080 hrs.	50.	30.	20.	15.	13.
Oil, waste and supplies per yr.	10.	6.	4.	3.	2.60
Total	174.70	130.	105.60	92.70	84.10
Without coal	92.20	64.	50.60	43.20	40.10
Coal, at $5.00	195.	146.50	119.35	105.07	95.10
" " 4.50	185.01	138.25	112.47	98.80	89.60
" " 4.00	174.70	130.00	105.60	92.70	84.10
" " 3.50	164.38	121.75	98.72	86.51	78.60
" " 3.00	154.06	113.50	91.85	80.32	73.10
" " 2.50	143.74	105.25	84.97	74.13	67.60
" " 2.00	133.42	97.00	78.10	67.95	62.10

Coal Consumption of Compound Condensing Steam Plant. W. H. Weston, Engineering Magazine, January, 1912, has given the following figures, for running 9 hours a day and 305 days per year, in tons of coal per year.

H.p.	Tons in round numbers
400	1,500
500	1,800
600	2,100
800	2,600
1,000	3,100
1,500	4,400
2,000	5,500
4,000	10,200
PLANTS WITH 2 ENGINES	
500	3,600
750	5,000
1,000	6,200
2,000	11,000
PLANTS WITH 4 ENGINES	
500	7,200
1,000	12,400

TABLE XVII. COST OF ONE STEAM H.P. PER BRAKE H.P. PER YEAR FOR MEDIUM SIZE COMPOUND CONDENSING ENGINES

Size of plant, h.p.	100	200	300	400	500	600	700	800	900	1,000	1,500
Cost of plant per h.p.	$170.00	$146.00	$126.00	$110.00	$96.00	$85.00	$76.00	$69.00	$64.00	$60.00	$58.00
Fixed charges, 14%	23.80	20.40	17.65	15.40	13.45	11.90	10.65	9.65	8.95	8.40	8.12
Coal per h.p. per hr.	7.00	6.50	6.00	5.50	5.00	4.50	4.00	3.50	3.00	2.50	2.00
Cost of fuel, $4.00 per ton	38.50	35.70	33.00	32.00	27.50	24.70	22.00	19.20	16.50	13.75	11.00
Attendance, 10-hr. basis, 3,080 hrs.	12.00	10.00	8.60	7.25	6.20	5.40	4.70	4.15	3.75	3.50	3.25
Oil, waste and supplies	2.40	2.00	1.72	1.45	1.24	1.08	.94	.83	.75	.70	.65
Total	76.70	68.10	60.97	56.10	48.39	43.08	38.29	33.83	29.95	26.35	23.02
Coal at $5.00 per ton	86.40	77.10	69.22	61.90	55.29	49.28	43.79	39.73	34.05	29.80	25.77
" " 4.50 " "	81.50	72.60	65.07	58.10	51.79	46.18	41.04	36.28	32.00	28.05	24.39
" " 4.00 " "	76.70	68.10	60.97	56.10	48.39	43.08	38.09	33.83	29.95	26.35	23.02
" " 3.50 " "	71.90	63.70	56.82	50.50	45.04	39.98	35.54	31.48	27.87	24.60	21.64
" " 3.00 " "	67.00	59.20	51.67	46.70	41.49	36.88	32.79	29.03	25.80	22.90	20.27
" " 2.50 " "	62.30	54.75	48.59	43.00	38.09	33.83	30.04	27.18	23.75	21.20	18.89
" " 2.00 " "	57.45	50.25	44.47	40.10	34.64	30.73	27.29	24.23	21.70	19.47	17.52

TABLE XVIII. COST OF ONE STEAM H.P. PER BRAKE H.P. PER YEAR OF 308 DAYS FROM 3,000 TO 6,000 H.P. IN SIZE

Size of plant, h.p.	3,000		4,000		5,000		6,000	
Cost of plant per h.p.	$54.00		$52.00		$50.00		$48.00	
Coal per h.p.-hr.	1.375 lbs.		1.25 lbs.		1.125 lbs.		1.00 lb.	
Fixed charges at 14%	$7.56		$7.28		$7.00		$6.72	
Fuel at $4.00 ton	10 h.	24 h.	10 h.	24 h.	10 h.	24 h.	10 h.	24 h.
Fuel at $4.00 ton	$7.46	$14.92	$6.87	$13.75	$6.18	$12.37	$5.50	$11.00
Attendance, 10-hour basis, 3,080 hrs.	2.75	5.50	2.50	5.00	2.25	4.50	2.00	4.00
Oil, waste and supplies	.50	1.20	.40	.96	.35	.84	.30	.72
Total, coal, at $4.00	18.27	29.18	17.06	26.99	15.79	24.72	14.52	22.44
" " " 3.00	16.40	25.45	15.40	23.56	14.24	21.90	13.14	19.69
" " " 2.50	15.47	23.50	14.38	21.84	13.47	20.22	12.46	18.32
" " " 2.00	14.54	21.72	13.76	20.12	12.69	18.53	11.77	16.94

Labor Costs in a Compound-Condensing Steam Plant. W. H. Weston, Engineering Magazine, January, 1912, gives the following figures based on 10 hours per day with wages as in 1911.

H.p.	Cost per year
400	$2,400
500	3,000
600	3,400
800	4,000
1,000	4,500
1,500	4,600
2,000	5,600
4,000	9,000

Fixed Charges in Compound Condensing Steam Plant. The following figures are taken from an article by W. H. Weston, Engineering Magazine, January, 1912.

Interest, insurance, and taxes	10 to 11%
Average depreciation on engine plants	4%
Average depreciation on boiler plants	5%
Average cost of repairs, depending upon age of the plant, intensity of the load and how it was handled, and whether or not repairs were promptly made	2 to 3%

Fuel and Water Consumption for Compound-Condensing Steam Engines of 1000 h.p. Upward. W. H. Weston, Engineering Magazine, January, 1912, states that engines of this class, of 1000 h.p. will ordinarily use 17 lbs. of water per h.p.-hr. with pressures of 125 to 135 lbs.; 2000-h.p. engines will use 15 lbs. and 4000-h.p. will use about 14 lbs. He has compiled the following figures from a large quantity of data where soft coals were used. Working to a fair maximum performance, without overcrowding and with average chimney draft of 0.43 in., the average coal per sq. ft. of grate per hr. is 19 lbs.; average water evaporation per lb. of coal, 8.65 lbs. Under ordinary running conditions, feed-water at an average temperature of 190 degs. F, flue gases 450 degs. to 550 degs.

$17 \div 8.65 = 1.96$ lbs. coal per h.p.-hr.
$19 \div 1.96 = 9.7$ h.p. per sq. ft. of grate.
$15 \div 8.65 = 1.73$ lbs. coal per h.p.-hr.
$19 \div 1.73 = 11$ h.p. per sq. ft. of grate.
$14 \div 8.65 = 1.62$ lbs. coal per h.p.-hr.
$19 \div 1.62 = 11.7$ h.p. per sq. ft. of grate.

In using these figures it is worthy of note that four 1000 h.p. engines will not run on as small an amount of water as one 4000 h.p. engine. The amount of coal burned per sq. ft. of heating surface will average 0.4 to 0.45 lb. per hr., or not over 0.5 lb. as a maximum. He considers that the amount for the best all-round efficiency is about 0.42 lb.

The average amount of water evaporated per sq. ft. of heating surface per hr. in water-tube boilers is about 4.2 lbs.; in tubular boilers, about 3.5 lbs.

To calculate the total amount of coal required for a plant, the figures given, 1.96, 1.73 and 1.62 respectively per h.p.-hr., must be

increased about 15% to allow for keeping fires over night, steam for auxiliary, condensation in pipes, radiation, etc., which will make them respectively 2.25, 2.00 and 1.86 lbs. Steam used for heating or other purposes will be in addition to this.

Compound-condensing engines of 800 h.p. will consume about 18 lbs. of water per h.p.-hr., and 2.08 lbs. of coal, 15% added for miscellaneous making 2.39 lbs. of coal per h.p. hr.

Similar engines of 600 h.p. use 19 lbs. of steam, and 400 h.p. equipment uses 20 lbs. of steam per h.p.-hr.

The average cost of oil, waste and small supplies for such a plant will amount in dollars to about 12 times the square root of the h.p. per yr.

The cost of water in a steam plant is a very uncertain quantity, depending upon local conditions; such as the success in eliminating oil, quality of the condensing water, whether jet condensers or the mixing type are used, the distance which the water must be piped or the height to which it must be pumped, etc., the average figures are not trustworthy. This item should be figured out for every special case.

Availability of Exhaust Heat from Different Types of Engines. The exhaust, be it steam or gas, contains heat, sometimes reaching 70 or 75%, and may be available for warming buildings, etc. The more efficient the engine, the smaller the amount of the exhaust heat available for this purpose.

Table XIX indicates what may be expected and was published by Edwin D. Dreyfus in Power, January 31, 1911.

TABLE XIX. STEAM PER BRAKE H.P. AVAILABLE IN THE EXHAUST FOR HEATING, LBS.

Type of engine	
Simple automatic engine	40
Small steam turbine	30
Single cylinder Corliss engine	28
Corliss non-condensing compound engine	22
Automatic bleeder turbine	20
Complete expansion turbine (bleeding 25% from receiver)	6
Gas engine (waste jacket and exhaust heat used in hot water system)	5
Gas engine only, exhaust applied to steaming	2

Summary of Operating Results in Steam Turbo-Electric Plants from 200 to 20,000 kw. Capacity. O. S. Lyford, Jr., and R. W. Stovel have given Table XX, Electric Journal, April, 1912.

This table gives the maximum results that may generally be expected with bituminous coal of 14,000 B.t.u. per lb. The annual average boiler and furnace efficiency ranges from 50 to 70%. In the 2 sets of assumed conditions, the additional heat necessary to bring the temperature of the feed-water of the one case up to that of the other is sufficient to raise the steam pressure of the second case to 65 lbs. more than the first and to superheat the steam 125 degs., the steam in the second case doing 10% more useful work

TABLE XX. SUMMARY OF OPERATING RESULTS

	Range of common practice	
B.t.u. per lb. of fuel (assumed)	14,000	14,000
Average yearly overall boiler and furnace efficiency, %	50	70
Effective B.t.u. per lb. of fuel	7,000	9,800
Boiler pressure, lbs. per sq. in., gauge	125	190
Superheat, degs. F.	0	125
Average feed-water temperature, degs. F.	120	200
B.t.u. per lb. of steam (approximate)	1,100	1,100
Lbs. of water evaporated per lb. of fuel, actual	6.36	8.91
Lbs. of fuel per standard boiler h.p. (33,305 B.t.u.)	4.76	3.40
Average overall station water rate per kw.	30	20
B.t.u. in coal per kw. generated	66,000	31,500
Thermal efficiency of station, %	5.2	10.8

than that in the first case, which emphasizes the importance of proper feed-water heating.

The water consumption for the main units and all auxiliaries will vary over a year between 30 and 20 lbs. per kw.-hour, which figures, divided by the rate of evaporation, will give the lbs. of coal per kw. generated between the limits of 2.25 and 4.72 respectively. These figures multiplied by 14,000 give, for the average over the entire year, the B.t.u. in the fuel per kw.-hr. generated. Since the kw.-hr. is theoretically equivalent to 3,420 B.t.u. the resultant annual thermal efficiency of the station will appear as the last two figures in the table, namely — 5.2 and 10.8%. A few stations to-day give better results than the best here indicated and a good many plants are worse than the 5.2% shown in the lower limit of this table, but a standard plant to-day ought to come lower than these two limits and if large enough ought to be very close to the better one.

Floor Space Required by Corliss Engines and Turbines. J. R. Bibbins gives the following information in a paper for the 25th Convention of the A. I. E. E.

For several years there has been a continual reduction in the bulk and cost of the turbine unit. To what extent, can best be appreciated by comparison with Corliss practice.

Type of prime mover and size in electric horsepower	Over-all floor space, sq. ft. per electric h.p.
Horizontal Corliss, 500 to 1,500	0.7 to 1
Vertical Corliss, 1,000 to 3,500	0.35 to 0.4
Horizontal vertical compound Corliss, 7,000	0.46
Vertical 3-cyl. Corliss, 5,000	0.2
Single-flow turbine, 1,000 to 5,000	0.17 to 0.75
Double-flow turbine, 15,000	0.05

In large sizes, the turbine has reduced floor areas to about 20% of that required by the modern vertical Corliss engine, and to about 10% of the horizontal vertical type. A detailed comparison between single-flow and double-flow types follows:

TURBINES

Unit size, kws.	Type	Floor space required per sq. ft. per kw.	per e.h.p.
1,000	Single-flow	0.200	0.149
1,500	"	0.165	0.123
2,000	"	0.141	0.105
3,000	"	0.101	0.075
5,000	Double-flow	0.092	0.068
10,000	"	0.063	0.047

Similarly in weight per kw. capacity. Data are not at hand for comparison with complete reciprocating units, but without generators, large vertical Corliss engines, including flywheel, weigh from 320 to 500 lbs. per kw., the weight increasing with the size, whereas the large turbine unit complete weighs but a fraction, 15 to 20% of the above, and, moreover, the weight decreases with the size. In addition the horizontal turbine permits the installation of auxiliaries beneath.

Cost of Power for Various Industries Under Ordinary Conditions. Engineering and Contracting, May 4, 1910. Twenty-five years ago the expression "cost of power" was fairly well defined as meaning the yearly cost per indicated h.p. if produced by steam; or power on the wheel shaft if produced by water for 10 hrs. a day and about 308 days a yr., or for 24 hrs. for the same number of days.

Since that time, when mechanical transmission of power by shafting, belting, ropes, etc., were about the only methods in use, there has been developed the electrical transmission of power now so commonly in use, with new units of power, as electrical horsepower and kilowatts.

Also there has now come into common use the steam turbine, for which there is no indicated h.p., the measurements of power from which must be brake horsepower, electrical horsepower or kilowatts. There is the power produced by water wheels, which is gross h.p., net h.p. at the wheel shaft and, when transformed into electric power, it is measured in electrical h.p. and kws.

New industries like public lighting and street railway companies have also come into existence. In these plants, the cost of power is affected very greatly by factors which were unknown to the type of plant which was common to industrial concerns of the past.

It is the object of this paper to explain briefly some of the reasons for the very great differences in the cost of power under various circumstances, and to treat the factors affecting the net costs to various industries of both steam and water power, and to give a few examples of these which have come up during the course of our own engineering practice.

Items in Cost of Power. Generally, the cost of producing power may be divided into 2 parts:

(1) *Independent charges*, or the part which is independent of the output, embracing fixed charges on the plant, as interest, depreciation, insurance and taxes, and, to a certain extent, repairs.

(2) *Proportional charges*, or the part which is proportional to the output, including such charges as coal, labor, supplies, etc.

Steam plants in general may be said to have low independent charges and high proportional or operating costs.

Water power plants are usually the reverse, with high fixed charge accounts and low operating costs.

Another item which should be mentioned as affecting the cost of power is what Dr. Steinmetz calls "reliability factor," which takes into consideration the spare machinery needed to insure continuous service. The charges on this spare equipment are apt to have quite a bearing on the cost of power in a central station supplying power for public uses, where reliability must be one of the chief considerations and more spare or duplicate plant is usually maintained than in a private plant. This same factor, too, may have quite an important bearing on the value of a water power privilege.

Factors Affecting the Cost of Power. The chief conditions which affect the cost of steam power are:

(1) Cost of fuel delivered to the furnaces.

(2) Amount of power produced.

(3) The load factor in its relation to fixed charges, whether the power is continuous and uniform, or intermittent and variable.

(4) The net cost of power is reduced considerably in some concerns where the waste heat of the power plant can be used in the manufacturing processes in the form of low pressure steam or warm water.

The chief conditions which affect the cost of water power are as follows:

(1) Fixed charges on the development.

(2) Amount of power produced in its relation to fixed charges.

(3) The load factor in its relation to efficiency of wheels, pondage and reservoir capacity.

(4) The cost of supplementary power necessary to make up for the fluctuations of the water power, if required.

Variation in Cost of Steam Power. Steam power costs the most per unit of power when produced in small amounts, and the cost is increased for fluctuating loads and when used for purposes where the load factor is small. By "load factor" we mean the average output in per cent. of the full capacity of the plant. The cost of power in very small amounts has been eliminated from this paper, and it has been assumed that the plants discussed for different uses are fairly large and of about the same capacity.

Steam power costs the least per unit of power for comparatively steady continuous loads, as for paper mills and other similar industries, and the cost may be still further reduced where there is use for exhaust steam or other by-products from the plant. Such conditions as the last are found in colored textile mills. Power costs the most in plants having a low load factor with a variable load and where there is no use for the by-products of the plant, as in a lighting or street railway plant. Between these extremes are various industries for which the cost of power will vary greatly.

Industries running 10 hours a day have a low load factor comparatively, but the load while on is often fairly steady, particularly in textile mills. Public service plants usually have a load factor

somewhat lower than textile mills, but the load is extremely variable, which is not nearly so favorable to economical operation as the textile load would be.

An example of the reverse of the procedure in a colored textile mill might be cited in the case of a steel mill, where the waste gases from the furnaces might be used in a steam or gas engine plant, thus making the net cost of power very low.

Power for Various Industries. So far as we know, the net cost of steam power is the least and the net value of water power (but not of water) also the least for colored textile mills of all of the important industries. This is due to the usually steady load and to the fact that the waste products from the steam plant are most valuable for manufacuring purposes to those industries. If the heat required is not obtained from the waste products, it must be obtained direct from a separate boiler-plant.

The net cost of steam power for textile mills gradually increases from the cost to the mill which can use all of the waste products, which will have the lowest cost, to the case of mill making white goods, where only exhaust steam for warming the building and drying the yarn on the slashers can be used. Next to this latter case in favor of net low cost are the industries of any nature where exhaust steam can be used only for heating. In order to give a general idea of the usual costs of power under ordinary conditions in this section of the country, an analysis of the cost of power for a station of 2,000 kws. capacity is given below. This station is similar to some which have been constructed within the last few years. Later on will be given some of the effects of by-products from the plant for manufacturing purposes.

Cost of Power for Textile and Similar Industries. Let us first consider the cost of power under the various conditions for textile mills, and from these cases an idea of the cost to various other industries can be derived.

As electric driving is becoming so common in textile mills, we will assume for the basis of these costs that the stations considered below will be electric and of 2,000 kws. capacity, composed of 2 1000-kw. units. The costs of power from this station will usually be given as so much per kw. In case it is desired to reduce this cost per e.h.p., divide by 1.34. To get its cost per i.h.p., multiply the cost per electrical horse power by about 87%, or the cost per kw. by about 65%. It must be remembered also that there is no spare apparatus in these plants. This may be considered as fair average practice at present for manufacturing plants, but of course would not be tolerated for public service plants where reliability is so necessary.

In making up the cost of power here, all charges have been considered except the interest charges on the cost of land. These charges would be very variable, depending on the location of the plant. The cost of land for the station has also been omitted from the cost per kw. of the station. There are many opinions as to the proper percentage to charge to depreciation, interest, etc. In making up these costs, interest has been taken at 5%; depreciation,

repairs on the apparatus, at 5%, and on the building at 2.5%; insurance and taxes at 1%, making a total of 11% on the apparatus and 8.5% on the buildings. This was for 10-hr. power. For 24-hr. power the depreciation and repairs on apparatus were taken at 13% instead of 11%. A small amount is added in both cases for incidentals.

These figures, of course, would not do for a station where the manufacture of current was the main product, as for public service plant, because here, during a period covered by 4% depreciation newer and more efficient types of apparatus might make it necessary to discard apparatus which was mechanically good. This course would not be so necessary in a manufacturing plant, where the saving of a small percentage of the cost of power is not of such vital importance as are some other considerations.

You will note that we say "cost of power as a straight power proposition." The reason for this is that the net cost of this power can be materially reduced by using the by-products from the plant for manufacturing purposes, as will be explained later.

Ten-Hour Power. With a steam engine plant with direct connected generators the cost of the plant per kw. of capacity is about $125. The cost of power from this station with coal at about $4.25 a long ton in the pocket or $4.75 on the grates, would be about $33 per kw. per yr. of 3,000 hrs., as for a textile mill, as a straight power proposition. This is equivalent to about $24.60 per e.h.p. per yr. and about $21.50 per i.h.p. per yr. This is equivalent to a cost of 1.10 cts. per kw.-hr.

If steam turbines are used instead of steam engines, the cost of the station will be reduced to about $105 per kw. capacity. The cost of power produced on steam turbines would also be reduced to about $29.50 per kw. yr., against $33 for the engine plant. A part of this difference is made up from the reduced cost of the station and apparatus and a part from the better economy of the turbines, which we have assumed are using superheated steam and high vacuum, which is common practice. The use of superheated steam is not common practice in engine plants, and the engine plant considered was assumed as not equipped with superheaters.

24 Hour Power. If steam power were to be generated for 24 hrs. a day for 6 days in a week or say 300 days a yr., as for a paper mill or other similar industries, the cost of power would be about $57.50 per kw. per yr. for the engine plant and about $53 per kw. per yr. for the turbine plant. These costs reduce to 0.8 cts. per kw.-hr. and 0.74 cts. per kw.-hr., respectively.

These figures should be compared with 1.10 cts. per kw.-hr. for the engine plant and 0.983 cts. for the turbine plant when producing 10 hr. a day power. The difference in the cost for the two kinds of power is due to the fact that practically the same amount of fixed charges is spread over a much greater number of kilowatt hours. There is also some saving in coal per kw. hour due to the elimination of banking of fires for a large portion of the time.

Load Factors. The power plant for the textile mill operating 10 hrs. a day, 300 days a yr., would have a load factor of about 40%,

while the plant operating 24 hrs. a day for 300 days would have a load factor of about 93%. These figures of course assume that the plants are just large enough to drive their loads. This assumption is hardly true, especially at present, when the use of electric transmission makes it easy to provide spare units. The term "load factor" as used here means the ratio of the actual kilowatt hours generated in a year to the number which would have been generated had the plant run at full load every hour in the year. It must be remembered also that for the industrial plants under consideration the load is nearly constant throughout the operating time, which means good operating conditions.

Public Service Plants. In a lighting plant for a city, even with the same load factor as for the 10-hr. textile mill, which would be high for most of these plants, the operating conditions would not be nearly so favorable as in a textile mill, as about the same amount of banking would have to be done, and the prime movers would have to operate at variable loads. This latter undesirable feature would not be so serious in a large station as in a smaller one, so far as the efficiency is concerned, as the variation could be more nearly cared for by varying the number of units and thus operating all of them at advantageous points.

The cost of power for this type of plant is more, other things being equal, than for a plant of the same size for a textile mill having the same load factor. This is due to the effect of variable load towards a reduction in efficiency, and because of the greater cost of plant and consequently greater fixed charges per unit of output. It should be borne in mind, however, that these public service plants are usually of a very large size and that their output delivered has to compete in price with the cost of power from very small stations. This would give the advantage all to the central station as far as the actual cost of making power is concerned. To the cost of making the power, the central station must add the cost of transmitting, distributing and selling it.

Effect of Use of Waste Products from Power Plant for Manufacturing Purposes. For many years it has been common practice to use the by-products, such as exhaust steam and warm water from the steam plant, for manufacturing purposes and for heating buildings, etc. It has been also common practice to take steam out of the receiver between the cylinders of a compound engine for these purposes. The saving from using the exhaust of a non-condensing engine, which would otherwise go to waste, is large, because there is no additional steam required for the engine unless the back pressure is increased. Any use of the steam is nearly all clear profit, and if all of it is used, the only part left to charge to power is the difference in B.t.u. due to the difference in pressure and the condensation in the engine cylinder, jackets, etc. The use of large noncondensing engines for producing power, except in special cases, is becoming comparatively rare, but the use of steam from the receiver of a cross-compound condensing engine for manufacturing purposes and for heating, etc., is a common practice.

Receiver Steam. Table XXI shows the amount of coal charge-

able to power when certain percentages of the steam entering the high pressure cylinder are taken out of the receiver. This table takes into consideration the effects on the economy of the engine of not passing all of the steam into the low pressure cylinder, cylinder condensation, etc. The percentages in the first column are the percentages of the steam passing the high pressure cylinder which is taken out of the receiver for manufacturing purposes. The second column is the total coal burned, and the third is the coal chargeable to power after deducting the coal chargeable to manufacturing:

% of exhaust steam used for heating purposes	Lbs. of coal per i.h.p. per hr., all coal charged to power	Net lbs. of coal per i.h.p. per hr. after deducting for exhaust steam used
0	1.75	1.75
25	2.06	1.50
50	2.38	1.25
75	2.69	1.00
100	3.00	0.75

If the mill did not obtain its power from steam, so that it could use the low pressure steam of the plant for manufacturing, it would have to maintain a boiler plant of sufficient size to produce an amount of steam equivalent to that bled out of the receiver. The amount of B.t.u. or its equivalent in coal chargeable to power is represented by the amount of work done by the engine, and the losses due to the presence of the engine. The cost of generating the rest of the steam is chargeable to the manufacturing processes. By cost of generating steam is meant the total cost, including coal, labor, fixed charges and supplies of all kinds for the boiler plant. The cost in the engine room does not vary with the bleeding of steam, except possibly in some very unusual cases.

Examples of Manufacturing Plants. A few examples of the reduction in cost of power due to the uses of the by-products from a steam engine plant and the bleeding of steam from the receiver may be of interest. These are all given for textile mills as a basis. The corresponding costs for other industries can be calculated from the table and curves when the amount of steam required is known.

In one colored cotton and silk mill the power to run the mill was about 1,800 i.h.p. and for manufacturing purposes about 25% of the steam for this was required in the form of steam from the receiver. This did not include the steam for heating the building, but the cylinder ratio was such that it was deemed unwise to bleed a greater amount of steam from the receiver. Assuming the cost of power $33 per kw. with no bleeding, we get cost chargeable to

power with 25% bled continuously $12.75 + $17 = $29.75. The saving then would be $33 — $29.75 = $3.25 per kw.-yr.; $12.75 is the engine room charge. This was for the use of low pressure steam alone. Probably another material saving could be made by using the overflow from the condenser for water for dyeing purposes, etc.

In another mill where much more dyeing was done, requiring a large quantity of hot water, also a large amount of exhaust steam for manufacturing and heating, the cost of power, if no steam and waste products had been used, would have been about $34 per kw.-yr.; but when the proper credits had been allowed for items chargeable to manufacturing purposes, the cost was reduced to about $26 per kw.-yr., or a reduction of about $8 per kw.-yr.

In a plain or white goods mill where no steam would be required for manufacturing other than warming the building and slashing, the saving to be effected by using receiver steam for these purposes would be about $2 per kw. About .6 of this, or $1.20, is for heating and the rest for slashing, so about $1.20 per kw. is the amount of the reduction which could be made in heating the buildings of an industry similar to a textile mill. The above examples represent fairly average conditions.

Several years ago in one mill there was an 800 h.p. simple, noncondensing engine exhausting into the dyehouse. If the dyehouse was running full, the firemen in the boiler room could not tell whether this engine was running or not.

In paper mills the usual custom is to drive the paper machines with simple, noncondensing engines, the exhaust from which is used in the drying cans. The net cost of this power for coal is very small. In some mills some steam is also taken from the receiver of compound engines for other low pressure work.

The Cost of Water Power. The cost of water power depends upon a great variety of factors, but the essential feature is usually the fact as to whether the combined result of all these factors is such as to make the cost of the development per horse power delivered a reasonably small amount so that the fixed charges shall not be excessive. In other words, the allowable cost of water power cannot be materially more than the net cost of producing the same amount of power for the same purpose in some other satisfactory manner, usually by steam.

There is an idea fairly common among laymen that water power is free or at least that after the development has been completed the cost of operation is practically nothing. This is not true because the fixed charges go on whether power is generated and sold or not. The largest item in the cost of water power is usually fixed charges. For instance, if a development should cost $125 per kw., the fixed charges alone would amount to about $12.50 per kw. per yr. whether the plant was operated or not.

Another idea is that if a development which is to produce 10-hr. power costs about $100 per h.p. if carried to its most economical point, it will be a safe investment, but that if the cost reaches $200 per h.p. it will be well to proceed cautiously before investing in it. In general this idea is well grounded, but it should not be

applied to all cases, as there are many factors affecting the cost of power and such great differences in the market that each case requires very careful study and general rules are not to be relied upon.

The cost of maintaining and operating a supplementary steam plant to make up for the shortage of power during low water and floods, the effects of droughts, transmission problems in the case of electric plants, etc., must all be carefully considered as factors properly affecting the actual cost of power delivered from the hydraulic plant.

For the reason that water powers usually have high independent charges they are more valuable for use on loads with high load factors than with low load factors and are hence more valuable for 24-hr. power than for 10-hr. power. Their value increases as the price of coal rises.

Many of the modern developments are of very large size and the cost per h.p. of the plant is in some cases small. In the determination of the cost of power, the cost per h.p. of development should not be allowed to confuse or cause misrepresentation of the actual cost of power delivered. Usually the larger the development installed, the smaller is the cost per h.p. of development, but it does not follow in all cases that the cost of delivered power will be smaller per h.p. After the engineers have made their estimates of the cost of physical structures for these developments, there must usually be added generous items for interest during construction, interest on cost before there is any return, rights of way, incidentals, promoting, etc. The neglect of considering items like these has caused several of the recent developments to get into disrepute.

There are usually more elements of chance and more unknown factors in a hydraulic development than in a steam plant, and these facts should be taken into consideration and properly cared for.

On the other hand, a development properly made and at a reasonable cost is a valuable asset and one which bids fair to increase in value if the price of coal increases in the future as in the past.

The prices of power where the development cost $100 and $200 per h.p. mentioned above do very well for the ordinary case in the eastern states. There are, however, some particular uses, like mining, for instance, where there is no supply of wood, and coal is expensive, where a high cost of development is warranted and a high price can be obtained for the power. For example, there is one development where the cost of power at some mines was from $150 to $200 a yr. A hydro-electric development was made and power delivered at about $100 a h.p., thus making a great reduction in cost to the mine owners and yielding a substantial profit to the electric company.

There is a development which cost about $400 a h.p. to develop. A small portion of this power could be disposed of at the mines for $75 a horse power with comparatively short transmission lines, but the remainder had to be carried a long distance and sold in competition with other power. The fixed charges alone on this development were about $30 to $35 a yr. a h.p., and the running expenses

were also high. It was impossible to produce power cheaply enough in this case to compete with other sources of powers and pay the fixed charges on the investment.

The following example is typical of many developments in New England streams with mechanical transmission of power. Compare the cost of producing 1,000 h.p. by steam and water power on an average stream at a fixed locality, where coal is $4.50 a ton delivered to boiler house, and the production of 1,000 h.p. by steam power alone at a chosen locality, where coal is $4 and $3.50 per ton delivered to boiler house.

The assumed power of the river varies in an average year so that for the driest month 490 h.p. will be produced by water, leaving 510 h.p. to be produced by steam; and for the other months in the year the water power varies so that for four months in an average year no steam power will be required at all. The average of this steam power will be about 238 h.p. for 8 months per yr.

In a dry year the minimum water power will be 250 h.p. It will be necessary to run the supplementary plant for about 8 months, supplying in an average year from nothing to 510 h.p. and in a dry year up to 750 h.p. In order to have such a plant run anywhere near efficiently and cost a reasonable sum, it should be of such a size as to be overloaded for a portion of the time and underloaded for the rest of the time. In this case a plant rated at 500 h.p. capable of 50% overloading would answer.

The water power plant will cost about $75 per h.p. of development, or $75,000.

The cost of the water power will be as follows:

Fixed charges on cost of plant, interest, depreciation, insurance, taxes and repairs, say 9%, $75,000 by 0.09	$6,750
Attendance and supplies	500
Cost of water power if no charge is made for water	$7,250

The cost of supplementary power is as follows:

Estimated cost of plant, 500 h.p. at $60	$30,000
Fixed charges at 11%	3,300
Average deficiency of water power, 338 h.p. for 8 months.	
Coal 338 h.p. by 2.10 lbs. by 205 days by 10 hr. = 650 tons at $4.50	2,925
Attendance	1,700
Oil, waste and supplies	200
Cost of supplementary steam power	$ 8,125

$7,250 + $8,125 = $15,375, total yearly cost of water power and supplementary steam power.

$15,375 ÷ 1,000 = $15.38 per h.p.

Compare this with the cost of 1,000 h.p. produced by steam alone where coal is $4 per ton. This power should easily be made for $20 a yr. a h.p., thus leaving a margin in favor of water power of

$20 — $15.38 = $4.62 a h.p. With coal at $3.50 a ton, the cost of steam power alone should be not over $18.50, with a margin in favor of water power of about $3 a h.p.

Variation in Value of Water Power. The value of a hydro-electric power to various industries will vary in approximately the same ratio as the cost of producing power in some other way, if considered as power pure and simple, without taking into consideration other important items affecting the business, which are sometimes more vital than the cost of power itself.

To illustrate the value and cost of power under different conditions it may be well to mention the two following cases:

A price for hydro-electric power was submitted to a colored textile mill, of 1.2 cts. per kw.-hr. After due consideration, it was decided that the mill could not afford to accept the offer, the principal reasons being:

(1) On account of the use of steam for manufacturing purposes and of the water of condensation for dyeing, the net cost of steam power would be less than the price of hydro-electric power.

(2) It was better for the textile company to own and control its own plant, if it had the capital to build it, which it had, than to purchase current brought over many miles of pole line, and be tied up to some foreign company.

The cost of power per kilowatt at the switchboard from the hydro-electric company for the operating time of the mill was about $36 per kw. per yr., and for the steam plant which the mill was proposing to install this cost was estimated at about $34 per kw.-yr.; but if the power had been bought from the hydro-electric company, the mill would have had to install and operate a boiler plant nearly as large as the one required for both power and manufacturing steam. It was estimated that the use of the waste products from the steam plant would reduce the net cost of the power at least $8 per kw.

In another case offers from two hydro-electric companies were made to furnish power. One offer was promptly turned down as being too high a charge. A second offer was to furnish current at 1.2 cts. per kw.-hr., which is the same price which was refused for the colored mill. For a plain cotton mill, however, it was decided to be proper to accept the offer of 1.2 cts. per kw.-hr.

The principal reasons for accepting this offer were:

(1) 1.2 cts per kw.-hr. equals about $36 a kw. per year, or $27 an e.h.p. delivered. This reduced back to i.h.p. equals about $23.50 per yr., which was very near the estimated cost of steam power for the quantity required and at the price of coal for this particular industry.

(2) The mill desired to postpone the expenditure necessary for a steam plant if it could be done without serious loss.

Relative Importance of Cheap Power. It is evident that where power is the chief product of a plant, and is sold as energy in the form of electric lighting or electric power, it is important to produce the output at the minimum price.

In most industrial plants power is a means used to produce other product, which is sold, and it is apparent that, other things being equal, the necessity for cheap power is more important where the cost of power is a large proportion of the cost of the product, as in electro-chemical works, and the least important where the cost of power is a small per cent. of the total value of the product.

Textile mills require considerable power to run them, and the method and cost of production of this power must be kept in mind in selecting a location for a new mill and in estimating the value of an old mill already located, but it should not be allowed to play too important a part in the decision.

The chief items of cost entering into the product of a mill are materials and labor. The cost of power in a fair sized mill should not be over 5 to 6% of the total value of the product. It is, therefore, far more important to locate in some place where operatives skilled in the particular kind of business to be carried on or who can be trained to this work can be obtained at reasonable wages, and where the cost of transportation of raw material and finished product is a relatively small amount, than it is to seek a location where cheap power can be obtained, but where the other items are lacking. A saving of 10% in cost of power would represent a saving of about 0.5% of the value of the product.

The relative importance of locating a plant with reference to cheap power increases as the ratio of the cost of power to the value of the product increases. The relative importance of locating a plant with reference to the supply of help decreases as the amount of help required decreases. These factors tend to make textile mills locate with reference to good help and the paper mills with reference to cheap power. The latter use less help per horse power than the former, and usually use the power for 24 hrs. per day. This causes water power to be more valuable to paper mills than to textile mills.

Standard Prices for Hydro-Electric Power. Sometimes this question is asked, "Is there any standard price for electric power delivered?" There does not appear to be any standard, the prices varying largely according to the amount taken. For small amounts large prices can be obtained. The price, of course, must have a close relation to that at which power from a steam station would be sold. The prices for power in large amounts, as for textile mills for permanent power, seem to vary between $20 and $25 per h.p. delivered for 10-hr. power, and for 24-hr. power $30 to $40 per h.p.

For surplus or secondary power which can be furnished for more than 6 months but less than 12 months a year, the charges cannot usually be more than at a rate of $10 to $15 a yr. a h.p. in large amounts for 10-hr. power, or say about $1 a month a h.p. for such time as it is furnished, for about all that is usually saved is coal, as the fixed charges are going on all the time in the steam plant, and often a portion of the steam plant is run all the time. In a recent case it was estimated that some colored mills could afford

TABLE XXII

Typical use of plants	Type of prime mover	Hours per year	Cost per year Kw.	Cost per year E.h.p.	Cost per year I.h.p.	Cost per kw-hr. ct.	Possible reduction from use of by-products for manufacturing
Textile mill	Steam engine	3,000	$33.00	$24.60	$21.50	1.10	$1.20 to $12.00
Textile mill	Steam turbine	3,000	29.50	....	....	.983	....
Paper mill	Steam engine	7,200	57.50	42.90	37.40	.80	1.00 to 18.00
....	Steam turbine	7,200	53.00	....	....	.735	....
Textile mill	Water power	3,000	26.70 to 33.50	20.00 to 25.00	....	.89 to 1.12	None
Paper mill	Water power	7,200	40.00 to 53.50	30.00 to 40.00	....	.55 to .75	None

to pay at the rate of about $15 per yr. for secondary power, where the power could be obtained about 10 months a year. This case represents fairly average conditions, where coal costs about $4 per ton and where the power is fairly steady from day to day, so that it is not necessary to keep a full force of steam plant help.

Conclusions. The average results of the costs of power in the vicinity as outlined in this paper would be about as in Table XXII.

Under the last column heading are given the possible reductions which may be made in the net cost of power by the use of by-products from the plant for manufacturing purposes. The extreme high saving from the engines would occur only when the engine was running noncondensing, which would be an extreme case.

The saving from the use of by-products from the turbine plants has not yet been determined. The condenser water can certainly be used, and probably quite a saving can also be made from bleeding low pressure steam.

Choice of Power for Textile Mills. Engineering Record, May 7, 1910. To assist the officials of textile mills in a general way in deciding upon the best motive power to use under their particular conditions, Charles T. Main presented a paper before the National Association of Cotton Manufacturers, in which he discussed the cost of steam, hydroelectric and purchased power. All figures were based on the assumption that the mill is electrically driven and the cost of steam power was taken as the basis for all computations and deductions. In considering the figures given in the following abstract of the paper it should be borne in mind that they are for textile mills, in which the load is fairly uniform and the service less severe than in most manufacturing lines.

Steam Power. In making up the cost of steam power, all charges have been considered, except interest and taxes on the cost of land. The fixed charges, including depreciation, repairs, insurance and taxes, have been assumed at 11%, and the running time of 50 weeks of 58 hrs. each, or 2900 hrs. a yr. It is assumed that there will be 2 steam turbine units in each plant.

TABLE XXIII

Size of plant, kw.	1,000	2,000	3,000	4,000	5,000
Cost of plant per kw.	$125 00	$110.00	$100.00	$95.00	$90.00
Total coal per kw.-hr., lb.	3.0	2.8	2.7	2.6	2.5
Yearly cost per kw., coal at $5	$39.00	$34.00	$31.50	$30.25	$29 50
Cost per kw.-hr. coal at $5, ct.	1.34	1.17	1.09	1.04	1.02
Yearly cost per kw., coal at $4	$35.00	$30.50	$28.00	$27.00	$26.25
Cost per kw.-hr. coal at $4, ct.	1.21	1.05	0.97	0.93	0.91

The principal items affecting the cost of steam power are as follows:

1, Cost of fuel delivered to boilers. 2, Amount of power produced. 3, Fixed charges on cost of plant, 4, Attendance and supplies.

5, The net cost is reduced in some concerns where the waste heat of the power plant can be used in the manufacturing processes in the form of low pressure steam or warm water.

In most textile mills the power plant will vary from 1000 to 5000 kws. capacity. With a modern plant, the figures in Table XXIII for cost of installation, Mr. Main states, are fair, when no steam is used for anything but power.

The cost per engine h.p. for installation and operation is .75 of the figures given per kw. To compare with equivalent cost per i.h.p., take 65% of the above figures given per kw.

It has been common practice for many years to use exhaust steam for heating buildings. The saving thus made is considerable. In the lack of more accurate data on bleeding turbines, we will assume that the savings by doing it are the same as for the steam engine. The reduction effected by the use of low pressure steam (for heating purposes) upon the cost of power is shown approximately in Table XXIV.

TABLE XXIV

% of steam used	Per kw.-yr.	Per kw.-hr., ct.
	Coal at $5.00	
25	$ 3.00 to $ 4.00	0.10 to 0.14
50	6.00 to 8.00	.21 to .28
75	9.50 to 12.00	.33 to .42
100	12.50 to 16.00	.43 to .55
	Coal at $4.00	
25	$ 2.40 to $ 3.20	0.08 to 0.11
50	4.80 to 6.40	.17 to .27
75	7.60 to 9.60	.26 to .33
100	10.00 to 12.80	.34 to .44

If a portion or all of the condensing water is used for manufacturing purposes, there will be a substantial reduction in the net cost of power, although not as great as by the use of steam.

Water Power. The chief items affecting the cost and value of water power are as follows:

1. The quantity of water and the uniformity of flow during the year or a succession of years. If the flow is variable, it must be supplemented by steam or other power, and the value diminishes as the need of supplementary power increases.

2. The head. The cost of development increase per horse-power as the head diminishes.

3. The location of the power has a large effect upon the value, but the ability to transmit power electrically has rendered useful and of value many powers which otherwise would be valueless.

4. In nearly all lines of textile manufacturing there are some uses for low pressure steam. The use of exhaust steam and overflow water from the condenser for these purposes tends to reduce the net cost of steam power, and therefore to reduce the value of water power.

The chief items in the yearly cost of power are: 1, Fixed charges, as interest, depreciation, insurance and taxes on the development. 2, The cost of supplementary power, if any is necessary to make up for the fluctuation in water power. 3, Attendance and supplies.

No definite sum can be fixed as the cost of water power, as this depends largely upon local conditions. As the chief cost is usually the fixed charges on the cost of the development, the first cost is the most important item for consideration.

In a development substantially made, the fixed charges for interest, depreciation, repairs, insurance and taxes, Mr. Main states, may be as low as 8% with a short transmission line to 10% for a long line. For the purposes of this paper, they are assumed at 9%.

$75 a h.p., or $100 a kw. would be considered a low cost of a development. Table XXV shows in a general way the cost of power under varying conditions of cost.

TABLE XXV. COST OF UNIFORM HYDROELECTRIC POWER

Size of plant, kw.	1,000	2,000	3,000	4,000	5,000
Assumed cost per kw........	$100.00	$100.00	$100.00	$100.00	$100.00
Yearly cost per kw..........	12.00	11.00	10.75	10.50	10.25
Cost per kw.-hr., ct..........	0.41	0.38	0.37	0.36	0.35
Assumed cost per kw........	$200.00	$200.00	$200.00	$200.00	$200.00
Yearly cost per kw..........	21.00	20.00	19.75	19.50	19.25
Cost per kw.-hr. ct..........	0.73	0.69	0.68	0.67	0.66
Assumed cost per kw........	$300.00	$300.00	$300.00	$300.00	$300.00
Wearly cost per kw.........	30.00	29.00	28.75	28.50	28.25
Cost per kw.-hr., ct.........	1.05	1.01	1.00	0.99	0.98

The above costs are for current on the switchboard in the generating station. Transmission losses for short lines would be roughly 5% and for long lines 10%. Adding 10% to the last set of figures in Table XXV, we have the cost at the end of the line, assuming the cost of plant and line at $300 a kw., shown in Table XXVI.

TABLE XXVI

Size of plant, kw.	1,000	2,000	3,000	4,000	5,000
Yearly cost per kw..........	$33.00	$31.90	$31.62	$30.80	$30.00
Cost per kw.-hr., ct..........	1.61	1.11	1.10	1.09	1.08

That portion of the power which is uniform and which can be depended upon all of the time is called "permanent power" or "primary power," and that power which is variable and cannot be furnished all the time is called "surplus" or "secondary power." The effect of variable power is the necessity of a supplementary plant of sufficient capacity to make up the deficiency of water power.

The fixed charges on the supplementary plant would go on whether this plant was used or not at 11% or $11 per kw.-yr. To

this must be added the cost of operating, which under a varying load would be less economical than regular steam power, and would cost about $2.50 per kw. a month, with coal at $5 a ton, or about $2 a month, with coal at $4 for such time as it is run.

These fixed charges would increase the cost of power per kw.-hr. for the yr. by about $11 divided by 2900 equals 0.38 cts., and the operating charge would increase the cost per kw.-hr. by at least $2.50 divided by 2900 equals 0.09 cts. for each month that the plant is run full.

The total cost of power in such cases would be approximately as is shown in Table XXVII.

TABLE XXVII. COST OF VARIABLE POWER AT SWITCHBOARD OF GENERATING STATION; HYDROELECTRIC PLANT COSTING $100 A KW. AND COAL AT $5 A TON

Size of plant kw.	Cost of hydro-el. power kw.-yr.	Fixed charges steam plant	Cost when steam plant is run for time shown One month	Two months	Three months	Four months	Five months
1,000	$12.00	$11.00	$25.50	$28.00	$30.50	$33.00	$35.50
2,000	11.00	11.00	24.50	27.00	29.50	32.00	34.50
3,000	10.75	11.00	24.25	26.75	29.25	31.75	34.25
4,000	10.50	11.00	24.00	26.50	29.00	31.50	34.00
5,000	10.25	11.00	23.75	26.25	28.75	31.25	33.75

Every $100 incerase in the cost of the hydro-electric development adds $9 a yr. in fixed charges to the cost of power per kw.

With coal at $4 a ton, instead of $5, the cost of supplementary power is 50 cts. less than for $5 for each month which the supplementary plant is run.

Thus a 1000-kw. plant, costing $300 a kw., costs $30 a kw. for steady power. If supplemented by steam to its full capacity for 5 months, with coal at $5, the total cost of power would be $53.50, and $51 with coal at $4.

(For other data on water power consult the index).

Comparison of Hydroelectric and Steam-Electric Power. Comparing the figures above given, Mr. Main has made the following deductions:

1. With transmission losses at 10%, a hydroelectric development producing uniform power should cost not over $300 a kw., including the cost of transmission lines and all other charges in order to compete with a steam-driven station located at the mill with coal at $5 a ton, except for the smaller plants. With coal at $4, the hydroelectric development should cost not over $250, except as noted above.

The above is on the assumption that the steam plant produces power only, with no allowances for any further use of the by-product.

2. With a hydroelectric development with a variable power, whose variation is so great as to require a supplementary plant of equal capacity to the hydraulic plant, and with coal at $5 a ton, the cost of the hydroelectric plant should not exceed the amounts shown in Table XXVIII.

TABLE XXVIII

Size, kw.	Coal at $5 a ton Months supplementary plant runs 1	5	Coal at $4 a ton Months supplementary plant runs 1	5
1,000	$250	$150	$200	$100
2,000	200	100	175	50
3,000	175	75	150	25
4,000	150	50	125	25
5,000	150	50	125	25

3. The figures in Table XXVIII would apply approximately to the "secondary" power. Having determined how much can be put into the development of the uniform power, it can be determined how much further the development could be carried to produce secondary power. All of the above is for power with no uses for exhaust steam and warm water.

4. The effect of the use of exhaust steam has been shown before as making a considerable reduction in the net cost of steam power.

With coal at $5 a ton, each 25% of exhaust used reduces the net cost per kw. a yr. about $3.50, and per kw.-hr. about 0.12 cts., and with $4 coal each 25% of exhaust used reduces net cost per kw.-yr. about $3 and per kw.-hr. about 0.10 cts.

The effect of this on a hydroelectric plant is to reduce the amount which can profitably be invested in the development by about $40 a kw. for each 25% of steam thus used, with coal at $5 a ton, and by about $30 a kw. where coal is $4 a ton, so that if 100% of the exhaust could be used, the maximum economical sum to put in the hydroelectric development of 1000 kw. capacity of constant power, with $5 coal, would be about $150, instead of $300, and with $4 coal, $125 instead of $250.

5. With a variable water power requiring a double plant of water and steam, the conditions might easily be such that it would not pay to consider the water power, as the cost of maintenance and operation of the double plant might exceed the cost of steam power alone.

Purchased Power. Many mills now have the opportunity of purchasing power. There are many advantages to the mill if such power can be purchased at a reasonable price, some of which are as follows:

In a new enterprise there will be required a smaller investment or the same investment can be used in machinery. Less space will be required. Some care may be removed from the manager. The company is able, by postponing the installation, to take advantage of any improvements in power plant equipment which may be made during the period when current is purchased.

In considering the purchase of power, the mill will, as a rule, determine the price it can afford to pay by estimating what it would cost to produce the power in its own plant.

Power Plants in Textile Mills. Engineering Record, Oct. 17, 1908. It has often been said that the managers of textile mills could not be interested in power plant economies to any marked extent

because the expense for power is only 3 to 5% of the total expenditures of the mill. While such a statement may have been true formerly, it does not apply to the present feeling regarding power plants, for the experience of recent years has shown that the economies possible in some of the old plants were a really large percentage of the net annual profits of the mills. This saving has arisen not only in the power station itself, but also in the mills, where the elimination of irregularities in speed and the betterment of artificial illumination have proved quite important in increasing output and improving products. This subject was discussed in much detail in a paper by Mr. Lewis Sanders, presented recently before the National Association of Cotton Manufacturers, from which the following notes have been taken.

In order to obtain the best results, Mr. Sanders advises separating the power and mill organizations. The sole business of the power plant force would be the generation of the power and steam required by the mill at the lowest possible cost.

In deciding upon the type of power plant to construct, or upon the improvement or replacement of an existing plant, the investment must be considered. A high-grade plant giving the maximum economy of operation, which may show the best investment value in a locality where coal is $4 per ton, may, where coal is $1 per ton, show a lower investment value than a less economical but cheaper plant.

Mr. Sanders suggests as a basis of fixed charges for mill power plants that they be charged with 10% depreciation and 6% interest, equivalent to 3% on the initial cost of the plant during the 10 yrs. that it is being written off. This gives 13% fixed charges to be added to the operating expenses in comparing the relative economies of several proposed designs of plants. Some may object that it is not proper to charge the interest on the investment as part of the operating expenses, as that forms part of the dividend returns on the capitalization of the mill, but it should be borne in mind that the mill is not in the power plant business and that it should treat its power plant more as if it were covered by a bonded indebtedness than as part of the stock capitalization.

If of two power plant designs the more costly is only able to effect economies that will pay its extra depreciation charges and 6% on the investment, then the plant involving the least investment had better be selected and the capital saved invested in securities where the capital will be in a more liquid form than if tied up in the power plant. In the case of a central station, on the other hand, under those same conditions it would be better to select the more costly plant. When alterations to an existing plant are contemplated, it may be necessary to charge the improvement with a higher rate of depreciation than 10%, owing to the fact that the life of the improvement might be limited by that of the old plant. In deciding to replace an old plant with a modern one, the new plant should be charged with the fixed charges on its investment, but the old one should not, because if the new plant does not show

economies sufficient to absorb its fixed charges, and to show a profit besides, it will not pay to make the change.

The rate of depreciation recommended, 10%, is not advised on any idea that the power plant machinery will be worn out in 10 yrs., as in fact most of it should last 20, under good management, and maintain its efficiency. It is advised because the advances in power plant equipment are so rapid that the plant may readily be obsolete in 10 yrs., and warrant replacement with a more economical type.

One mistake Mr. Sanders has observed to be made with sufficient frequency to justify calling attention to it, lies in the calculation of the savings that will be made by improvements that will reduce the power consumption of an existing mill. Take the case of a mill with a power consumption of 10,000 kw.-hrs. per day, and in which improvements are in contemplation that will save 500 kw.-hrs. per day. Suppose the cost of generating power in that mill is known to be 1.5 cts. per kw.-hr., including all fixed charges. The mistake is frequently made of supposing that the saving of 500 kw.-hrs. will, therefore, mean a saving of $7.50 per day. As a matter of fact the saving will probably be nearer $2.50 per day, as the only item of the power plant costs that will be affected will be the coal consumption, labor and fixed charges not being reduced. Of course there are often changes that do mean a reduction in the labor item, but every case should be figured carefully to determine what the real saving will be.

The saving to be effected in the power plant of a belt-driven mill, by merely changing from belt drive to electric drive, will in very few cases warrant the change, according to Mr. Sanders. If, however, the proposition be taken up more fully and the opportunity be taken to completely redesign the entire power plant, then the economies that can be effected will very frequently be found to justify changing the entire installation. Again, in deciding what prospective gain there is in changing a belt-driven mill to electric drive, the effect on the production of the mill should be taken into account. The speed of every individual machine in the mill should be determined, to ascertain how many run below the maximum permissible speed. Suppose the introduction of the electric drive will increase the mean speed of the machines 2% besides giving a more uniform speed, the mill production will be increased by about that amount, without any increase in machinery or operatives, and possibly with less expense for repairs. This item alone will in many cases warrant electrification.

As the discussion of a concrete case is of more interest than abstract ideas, Mr. Sanders stated at some length the results of an investigation, conducted by his firm, on the power plant of a large mill. The plant consists of three separate stations, known as A, B and C.

Boiler plant A contains 12 Manning boilers of 196 h.p. each, Roney stokers, Green economizers, natural draft, closed heater. Capacity of plant, 2,350 b.h.p., steam pressure 100 lbs.

Boiler plant B contains 7 Manning boilers of 175 h.p. each, hand fired, herringbone grates, smoke consumers, Green economizer, open heater, natural draft. Capacity of plant, 1,225 b.h.p. Steam pressure, 100 lbs.

Boiler plant C contains 6 Manning boilers of 175 h.p. each, hand fired, Parsons grate system with a steam jet forced draft, Green economizers, open heater. Capacity of plant, 1,050 b.h.p. Steam pressure, 180 lbs.

Engine plant A contains 1 twin, simple, noncondensing Corliss engine, geared to shafting. The exhaust of this engine is used for heating water, which is used for boiler feed, washing and other purposes. Engine develops about 800 h.p.

Engine plant B contains 1 twin-tandem compound, condensing Corliss engine, geared to shafting. Engine develops about 1,375 h.p.

Engine plant C contains 1 cross-compound condensing Corliss engine of about 450 h.p., belted to a 300-kw. Bullock generator, one 750-h.p. cross-compound condensing Corliss engine belted to a 600-kw. Crocker-Wheeler generator, and one 400-kw. Westinghouse-Parsons turbo-generator. All generators are 2-phase, 60-cycle, 440-volt.

All the water for the plant is supplied by a central filter plant. Two centrifugal pumps are belt-connected to engines of about 50 h.p.

Besides the incandescent lamps there are a number of series arcs operated from 9 Brush arc machines, belt driven by the A engine.

Besides the steam used for power, a large quantity is used for manufacturing purposes, such as boiling dye-kettles, scouring, washing, tentering machines, etc. Live steam is used for all these purposes and for heating. The only use made of exhaust steam is the water heated by the exhaust of the A engine and about half of this water is used by the boiler feed.

The tests comprised 2 boiler tests of 3 days' duration each on the A boiler plant, a 24-hr. boiler test on the B plant, tests on the C boiler plant.

All the steam used for manufacturing purposes was metered by means of steam meters. Indicator cards were taken on all engines for several hours and the friction and live loads determined. As all engines were connected to jet condensers and two of the boiler plants supplied steam for manufacturing purposes, besides supplying the engines, it was necessary to approximate the steam consumption of the engines. This was done from the indicator cards and the measurements of steam supplied by the boilers and that accounted for by the steam meters. It was not possible to meter the steam used by the engines, as the meters are not accurate on a pulsating flow of steam. In fact, the pulsations set up by the engines disturbed the readings of the meters on the pipe lines supplying steam for manufacturing purposes. It was, therefore, necessary to make approximate corrections in determining the amount of steam used at various points; while the total steam consumption of the plant was correct, this being determined from the boiler feed, there may have been individual errors of 5% in the distribution.

From the regular test results on the boilers and engines financial balance sheets were prepared on the operation of the plant. These give the results in dollars per yr., which will probably interest the mill owner more than figures of evaporation. Each balance sheet is prepared on the basis of charging the plant with the cost of all coal and labor, and then showing the distribution of this sum in the various operations of the power plant. All losses, both the necessary and the unnecessary, are shown and their amount. First, the cost of the coal burned is shown, then the cost of the steam generated. From this the avoidable losses are deducted showing the net value, and this is also given per 1,000 lbs. of steam. Then the distribution of the steam is given, on the basis of its net value. The amount of useful steam is determined and from this the net value of the useful steam. The useful steam is that which is used by the engines and for manufacturing purposes. Steam used for boiler feed pumps and other auxiliaries is not useful to the mill; it is part of the power plant expense.

This method of analysis shows the efficiency of operation and the efficiency of plant design. For instance, we burn $100,000 worth of coal, including the cost of firing; 75% of the heat of this coal should be utilized in generating steam, if the plant is operated as it should be, and 25% would be discharged in the flue gases. Now if the power plant were operated so that only 70% were utilized in making steam, the balance sheet would show $70,000 used to evaporate water, $25,000 properly discharged into stack and $5,000 wasted into stack. The waste of that $5,000 does not increase the value of the steam produced, it only increases the cost, so that the cost of the steam is shown as $100,000 and its net value as $95,000. Again, two power plants may produce steam at the same cost, but one may use 15% of this steam for its auxiliaries, while the other may use only 10%, making the cost of steam furnished the mill quite different in the two cases. It is the power plant that delivers steam and power to the mill at the lowest cost that is the most economical, and this is not always the one that is showing the highest evaporation per pound of coal and the lowest steam consumption per indicated horse-power.

The balance sheets show the following losses due to the character of the plant, and which could only be avoided by different design: Combustible wasted by stoker grates, $1,130; steam used by jets under stoker, $6,555; steam used by jet blowers in A, $2,045; total, $9,730.

The following losses were avoidable and are chargeable to faulty operation: Loss due excessive price paid for coal, $14,000; loss due excessive air used in combustion, $2,573; loss due leaky dampers on economizers, $1,595; loss due use of smoke consumers, $1,710; loss due leak in feed water heater, $1,110; loss due steam wasted by turbine, $5,500; total, $26,488.

Proper purchasing of the coal would save $14,000. Improved operation that eliminated all the other losses would not save the remaining $12,500 wasted, because only the coal involved would be saved, as the reduction of steam consumption would not be suffi-

cient to dispense with the services of a fireman. This would result in increasing the cost per 1,000 lbs. of the remainder of the steam, as the percentage of labor expense would be increased. The actual saving due to eliminating all the losses due to operation is therefore about $11,000 out of the $12,500 wasted.

With regard to the possibility of effecting these savings, it should be noted that, with one exception, the losses are due to undetected defects of apparatus, and that their remedy does not put a continuous strain on the operating force. The exception is the loss due excessive air going through the furnaces; this was largely due to such things as carelessness in keeping the hoppers on the stokers filled and the ash pockets sealed. The opinion on what is attainable in this respect is not based on what can be accomplished during a short test run, but on what the firemen have proved they could accomplish without undue strain. All three boiler plants were equipped with instruments for automatically making and recording an analysis of the flue gases every five minutes. The opinions are based on a series of records extending over 2 months, in which the men showed repeatedly that they could maintain the standard here adopted, without being specially urged at their work.

The figures in Table XXIX, taken from the balance sheets, give a comparison of the economic value of the 3 power plants. They give the comparative costs of operation per unit of power and steam supplied, after deducting all costs due to a failure to operate that particular plant at its maximum efficiency. The differences in costs are therefore due to the difference in design of the plant. The costs are based on the use of Pocahontas coal at $4 per ton.

TABLE XXIX. OPERATING EXPENSES OF THREE POWER PLANTS, AFTER DEDUCTING EXPENSES DUE TO FAILURE TO RUN AT MAXIMUM EFFICIENCY

Plant	A	B	C
Coal as burned, including labor per ton	$4.50	$4.72	$4.55
Steam generated, per 1,000 lb.	20.0 ct.	22.6 ct.	22.2 ct.
Steam available for power, manufacturing and heating, per 1,000 lb.	25.9 ct.	25.2 ct.	25.35 ct.
Power, per 1,000-b.hp.	$2.30	$4.40	$4.27

These comparative costs disclose a curious condition. The A boiler plant is distinctly a modern plant and shows an economy over the other two plants of some 10% in the cost of generating steam, yet it is the most expensive plant for the mill to operate. This is due to the amount of steam the boiler plant itself consumes. The B plant, which is actually the most expensive to operate from the standpoint of water evaporated, proving to be the most economical for the mill's use. The B boiler plant is the most efficient of the 3 plants as regards water evaporated per pound of coal, but becomes the most expensive on the basis of cost of evaporation, owing to the fact that it contains 7 boilers and requires 3 firemen, while the C plant has 6 boilers and runs them with 2 firemen. We have here a fixed increase in operating ex-

pense due to nothing but the size of units selected. The same conditions are shown in the engine plants; A, which uses the most steam per h.p is the most economical because it returns a large part of the steam to the mill for manufacturing use. The C engine plant should show a greater economy than it does over the B, on account of its more efficient engines. The reason that it does not is due to the layout of the C plant being such that it requires three men on shift, while B has two men and generates about the same amount of power.

The C power plant satisfies the requirements of location for a new station exceedingly well. It is located between the dye house, tentering machines and the scouring plant. This puts it as near the center of steam consumption as the construction of the mill permits. There is room in the present C engine and boiler rooms to contain the entire new plant, so no new buildings will be required There is available ground for enlargement to a plant 3 times the size, and this without interfering with the growth of any of the mill buildings. Ample coal storage can be provided and the railroad siding is now located at this point.

The new plant will be equipped with turbines, from which steam will be drawn at 45 lbs. pressure for the tentering machines and carbonizing, and at 5 lbs. pressure for dye house, scouring, heating, etc The size of unit adopted for boilers and turbines is as large as possible consistent with having the units of such size that if any one unit breaks down the remaining units can carry its share of the load on their overload capacity. The size of the unit must also be selected with reference to the load at various times, so that the units in service shall operate as nearly as possible at their rated capacity in order to secure the highest economy. In this case we have a load of 2,200 kws. for 58 hrs. a week and a load of 344 kws. for 67.5 hrs.

The plant recommended, in this instance, consists of 3 double-ended water-tube boilers of 1,000 h.p. each, combined forced and induced draft, hand-fired furnaces, this to give the greatest adaptability of the plant to various grades of coal. Coal storage for about 3,000 tons with coal-handling apparatus for unloading coal and handling it from stock piles to boiler room floor, and also for ash removal. The turbines recommended are 3 vertical turbo-generators of 750 kw. capacity each, with special modifications in construction to suit these conditions. As part of the plant is already electrified, the 2-phase, 60-cycle, 440-volt system would be continued, otherwise 3-phase, 60-cycle, 600 volts would have been recommended. The parts of the existing plant that would be utilized are the buildings of C boiler and engine house, the economizers, possibly some of the auxiliaries, some of the piping in the mill buildings, and the motors and wiring. The Westinghouse turbine would be retained for reserve and to provide for any moderate growth in the power demands.

The engines in the filter plant will be replaced by motors with automatic control, and the arc machines will be eliminated and the

arcs replaced with high efficiency incandescent lamps. This will dispense with the two attendants at these plants. The cost of this plant, including motors, would be about $150,000.

The new plant with the auxiliary apparatus will do the work now performed by 3 power plants containing 23 boilers, 4 engines, 1 turbine and the auxiliary apparatus in triplicate. The existing plant has no coal storage and all coal has to be teamed to the boiler rooms. The removal of the 2 power plants that would be abandoned will make available considerable ground for mill buildings.

The present plants require 33 men to operate them, while the new plant, when running the same grade of coal, will require only 13 men, and with No. 3 buckwheat 16 men, and if stokers are used, only 7 men for its operation. These figures do not include superintendence nor the machine shop and pipe fitters forces that are used when repairs are necessary. The new plant should show a decrease in these items.

The coal consumption for the new plant would be 18,740 tons of soft coal or 22,600 tons of No. 3 buckwheat coal, as against 27,200 tons of soft coal for the present plant. Table XXX gives the operating costs of the new plant under several conditions. In the cost of labor for the new plant the engineers are figured at a higher rate of pay than they are receiving in the present plant, but no higher efficiency has been counted upon.

TABLE XXX. ANNUAL OPERATING CHARGES OF NEW PLANT

Coal used, grade	Soft	No. 3 Buck.	No. 3 Buck.
Coal cost, per ton	$4	$2.70	$2.70
Coal, tons	18,740	22,600	22,600
Firing	Hand	Hand	Stokers
Labor	$10,250	$12,475	$5,980
Removing ashes	610	1,415	1,415
Total annual cost	85,860	74,890	68,395

The operating costs of the present plant are given, about $150,000 per year, not including repairs, superintendence, oil or supplies.

In the operation of the mill large quantities of hot water are discharged to the sewer, at temperatures ranging from 100 degs. to 200 degs. from dye kettles, scouring, etc. It is assumed that 20% of this waste heat can be recovered. The installation of the necessary apparatus to recover this heat might raise the cost of the plant to $200,000. If this 20% of the heat discharged to the sewers is recovered and at the same time the efficiency of operation of the plant be raised to the maximum possible, by means of bonus payments to the men for excellence of operation, the operating costs would become, with the plant operated on the No. 3 buckwheat coal at $2.70 per ton and the use of stokers: 19,150 tons coal, $51,700; labor, $5,980; removing ashes, $1,190; bonus paid men for high efficiency, $1,200; total, $60,070.

It is now possible to figure the costs per unit for the new plant, to compare the economic value of its design with that of the three

existing power plants at the mill, which were given in Table XXIX. They are given below:

Operating expenses of proposed power plant, with soft coal at $4, hand-fired, or No. 3 buckwheat coal at $2.70, stoker fired:

Coal used	Soft	Buck.
Coal as burned, including labor	$4.42	$2.85
Steam generated per 1,000 lb.	19.7 ct.	15.5 ct.
Steam, available for mill	20.8 ct.	16.35 ct.
Power, per 1,000 b. hp.	1.98	$1.60

It should be particularly noted that the reductions in costs for the new plant are due entirely to the design of the plant, and are not based on any expectations of improved operation or of cheaper coal, in so far as the comparison of the plants when using soft coal is concerned.

If we take the cost of the new plant as $150,000 and the saving in operating costs as that shown by operating with soft coal, hand fired, viz., $59,696 per year, we have: Depreciation, 10%, $15,000; interest 6% on average outstanding investment, $4,500; net saving due to new plant, $31,196; net return on investment, 20.8%.

The mill possesses a record system that is about the same as to be found in most mills. It shows the coal and water used each week and the power generated. It showed nothing at all of the various defects in the power plant nor gave any means of detecting them, yet that is the only reason for having a record system. If the records had been of any value they would have called the attention of the owners to every one of the $26,000 of losses going on in the power plant, including the high price being paid for coal.

Mr. Sanders strongly believes in the use of recording instruments throughout the power plant, as it can then be run on a continuous test basis. If the records are not properly analyzed and if every defect of apparatus or of operation that they detect is not immediately remedied, the use of the recording instruments or a record system is a waste of money. If the results are utilized, the money invested in recording instruments will prove a paying investment.

Cost of Steam and Electric Power for Operating Flour Mills Producing 54,000 Bbls. of Flour Per Yr. Charles A. Stanley gives the following notes for the plant using oil and coal, according as the prices thereof vary, in Oct., 1912, Proceedings of Kansas Gas, Water, Elec. Lt., & St. Ry. Ass'n.

Investment — Fixed charges:

Power plant buildings	$2,000
Engine	900
Boilers	1,200
Miscellaneous	800
	$4,900
Depreciation, 6%	$294.00
Interest, 5%	245.00
Taxes, 1%	49.00
Insurance, 1½%	73.50
	$661.50

Fuel:	
Coal and oil, including handling	$2,500.00
Labor:	
Engineer	1,300.00
Water:	
Pumped from well. Softener included in repairs.	
Superintendence:	
Time of miller and office help, ½ hr. per day at 50 cts. per hr.	75.00
Loss of Production:	
½ hr. per week; time of 5 men at 25 ct.	65.00
Repairs and Supplies:	
Oil, waste, etc.	100.00
Total	$4,701.50

Cost per bbl of flour, 8.7 ct.

The above mill is using a non-condensing engine, simple Corliss type, belt-driven to line shaft. The engine indication shows 85 hp. on full load. This results in 2,040 hp.-hr. per day for 250 bbl. output, or 6.1 kw.-hr. per bbl.

Losses in present plant:	
Steam driven, 15%	11.75 h.p.
Belt drive, 8%	6.80 h.p.
Total	18.55 h.p.

If this plant is equipped with a 100 h.p. motor, the power required for operation will be about as follows:

Motor power		85 h.p.
Less present losses		18.55 h.p.
		66.15 h.p.
Plus motor loss, 10%	6.65	
Plus wiring loss, 2%	1.3	
Plus drive, loss, 3%	1.9	
		9.85 h.p.
Electrical power required		76.3 h.p.

The above 76.3 h.p. equals 57 kws., which operated for 24 hrs. producing 250 bbl. of flour, results in 5½ kw.-hr. per bbl.

The cost of operating this mill from central station service per year will be about as follows:

Investment:	
Motor building	$ 250
Boiler room	250
Boiler for heating	280
Motors	1,200
Installation	300
Drive	285
	$2,565

Depreciation, 6%	$153.90
Interest, 5%	128.25
Taxes, 1%	25.65
Insurance, 1½%	38.48
	$346.28
Fuel:	
For heating and tempering	300.00
Labor:	
Fireman and motor care	100.00
Water:	
Pumped from well.	
Superintendence	25.00
Loss of production:	
None.	
Repairs and supplies	100.00
Electric energy:	
297,000 kw.-hrs. at 1.2 cts.	$3,564.00
Total	$4,435.28

The following data show several mills now operating from central station service — the cost of operation with their isolated plant, as previously equipped, also the cost at present, using central station service.

Mill	Capacity	Isolated plant Cost per ct. ct	Central station service Cost per bbl. ct
No. 1	350	9	8
No. 2	600	7.2	6.1
No. 3	900	6.8	5.9
No. 4	1,000	6.5	5.3

BELT DRIVE

Motor, 200 hp., slip ring, 600 rev. per min.	$1,700
Belt drive	300
Installation	250
Investment	$2,250
Motor house or space	750
Total investment	$3,000
Interest, depreciation, taxes and insurance, 13½%	405
Motor efficiency, 92% = 12 kw. loss	
Belt drive, 87% = 19½ kw. loss	
Total loss. . . . . .21½ kw. loss =	1,260
Total fixed charges and losses	$1,665
Power factor — 88%.	

ROPE DRIVE

Motor, 200 hp., slip ring, 600 rev. per min.	$1,700
Rope drive	600
Installation	250
Drive investment	$2,550

Motor house or space	1,000
Total investment	$3,550
Interest, depreciation, taxes and insurance, 13½%	479.25
Motor efficiency, 92% = 12 kw. loss	
Rope drive 90% = 13½ kw. loss	
Total loss.........25½ kw. loss =	1,080.00
Total fixed charges and losses	$1,559.25
Power factor — 88%.	

DIRECT CONNECTED

Motor 200 hp. slip ring, 180 rev. per min.	$3,000
Installation	250
Drive investment	3,250
Motor house or space	300
Total investment	$3,550
Interest, depreciation, taxes and insurance, 13½%	479.25
Motor efficiency, 86%, 21 kw. loss	840.00
Total fixed charges and losses	$1,319.25
Power factor — 88%.	

DIRECT CONNECTED

Motor 200 hp. slip ring, 180 rev. per min.	$3,000
Installation	250
Drive investment	3,250
Motor house or space	300
Total investment	$3,550
Interest, depreciation, taxes and insurance, 13½%	479.25
Motor efficiency, 86%, 21 kw. loss	840.00
Total fixed charges and losses	$1,319.25
Power factor — 85%.	

CHAIN DRIVE

Motor 200 hp. slip ring, 600 rev. per min.	$1,700
Chain drive	400
Installation	250
Drive investment	$2,350
Motor house or space	300
Total investment	$2,650
Interest, depreciation, taxes and insurance, 13½%	357.75
Motor efficiency, 92% = 12 kw. loss	
Chain efficiency, 98% = 3 kw. loss	
Total loss.........15 kw. loss =	600.00
Total fixed charges and losses	$ 957.75

The efficiencies given were taken from tests coming under Mr. Stanley's observation.

Loss of production is an item Mr. Stanley calls attention to in an interesting way.

Take a 250 bbl. mill, operating from a steam engine, in which repairs of a minor nature, such as renewing belts, changing pulleys, etc., must be made, generally on Sunday, which involves waiting until Sunday morning when steam is on to try out the mill after

the changes have been made. This requires an average of 1 hr. loss per week, and 5 men at $0.25 per hr. averages a yearly loss in labor of $75, added to which is the loss of production per week which means about 500 bbls. per yr.

Power Required. The size of motor required in flour mills depends on the type of machinery, etc., and in general will average about as follows, and is for mill only and does not include elevator:

Bbl. per 24 hr.	Soft wheat, h.p.	Hard wheat, h.p.
100	40	50
125	50	60
150	60	75
175	75	100
250	100	125
300	125	150
500	175	200
750	250	300
1000	300	400

Typical Solution of the Power Plant Problem for an Assumed Industrial Plant in Canada. Aldis Hibner of the Toronto Electric Light Company presented a paper at a joint meeting of the A. S. M. E. and A. I. E. E. in March, 1911, of which the following is an abstract.

In every industrial-power problem there are 3 main factors: 1, the investment charges; 2, operating charges; 3, the cost of heating or the use of low pressure steam. The first covers interest, amortization, insurance, taxes and profit on the invested capital. The second covers coal, labor, repairs and supplies, and the third includes investment and operating charges of the boiler plant necessary to heat the building, supplying steam for manufacturing processes.

Assuming a typical case of a shoe company, intending to build a new factory having a floor area of 60,000 sq. ft., and a cubical content of 750,000 cu. ft., the first step in the solution is the determination of the cost of heating which is necessary, the conditions of manufacture being such that the temperature of the building must be kept above 50 degs. during the winter months.

The coal consumption is based on an evaporation of 7 lbs. of water per lb. of coal, one change of air per hr. in the factory and the supplying of radiation losses. For this, 90 h.p. will be required in zero weather. Table XXXI gives the necessary investment, with the fixed and operating costs of the plant, depreciation being provided for by a sinking fund drawing 5% semi-annually.

TABLE XXXI

HEATING PLANT INVESTMENT

Boiler, piping and auxiliaries (A)	$1,500
Building and stack (B)	2,250
Total investment	$4,000

FIXED COST

Interest, 6% on $4000	$240.00
Insurance and taxes, 2% on $4000	80.00
Amortization on A, 4½%, 15 yr. life	67.50
Amortization on B, ½%, 50 yr. life	12.50
	$400.00

OPERATING COST

Coal, 475 tons at $3.00	$1,425.00
Fireman at $15.00 per week	780.00
Supplies and repairs	100.00
	$2,305.00
Total cost	$2,705,000

Fireman's time was figured for the entire year, since high pressure steam is necessary for industrial purposes.

The concern has a maximum capacity for 100 kws. of power, the average load is 80 kws., giving an 80% 10-hr. load factor. The

TABLE XXXII

COMPLETE POWER PLANT INVESTMENT

Capacity, 100 kw.

Engine, generator, switchboard, wiring (A)	$ 5,500
Boilers, steam piping, auxiliaries (B)	5,000
Building, foundations, stack (C)	5,000
	$15,500
Steam-heating plant	4,000
Additional for power	$11,500

FIXED COST OF POWER PLANT

Interest, 6% on $15,500	$930
Profit, 5% on $11,500	575
Insurance and taxes, 2% on $15,500	310
Amortization on (A), 3% (20-yr. life)	165
Amortization on (B), 4½% (15-yr. life)	225
Amortization on (C), ½% (50-yr. life)	25
	$2,230
Fixed cost on heating plant	400
Additional for power	$1,830

OPERATING COST OF POWER PLANT

240,000 kw.-hr.

Coal at 7.39 pounds, 887 tons at $3.00	$ 2,661
Banking, 181 tons at $3.00	543
Night heating, 202 tons at $3.00	606
Engineer at $18.00 per week	936
Fireman at $15.00 per week	780
Water	100
Oil, waste, supplies	150
Repairs	200
	$5,976
Operating cost of heating plant	2,305
Additional for power	$3,671
Total additional for power	5,501
Cost per kw.-hr.	0.0229
Cost per hp.-yr.	51.40

engine is of the Corliss non-condensing type, requiring 30 lbs. of steam per i.h.p.-hr. The evaporation at 7 lbs. of water per lb. of coal gives a coal consumption of 4.3 lbs. per i.h.p.-hr., and the efficiency from steam cylinder to switchboard is 78%, giving a coal consumption of 7.39 lbs. per kw.-hr. or 5.51 lbs. per h.p.-hr. at the switchboard, the factory running 300 days per yr.

Table XXXII gives the investment cost, fixed cost and operating cost of the plant, allowance being made for the cost of heating, as calculated.

Among the items of fixed cost is one covering profit on the additional investment required for a power plant. A concern is not justified in investing in a power plant unless the capital so invested returns the same profit as if invested in the most profitable part of the business still capable of extension. Considering the added risk this can safely be raised to 10 or 15%, and hence, it is evident from these results that if power can be purchased for 2.3 cts. per kw.-hr. there is no advantage of installing a steam-power plant.

Mr. Hibner quotes the U. S. Geological Survey report on gas-producer plants as showing that a non-condensing steam plant requires 2.7 times as much coal per unit as a producer plant, giving a maximum attainable efficiency for the producer plant of 21.5% as against 10.3% for the steam plant; the Corliss non-condensing engine basis requiring 30 lbs. of steam per i.h.p.-hr. The assumed requirements are for a shoe company with a floor area of 60,000 sq. ft. and cubical contents of 750,000 cu. ft., under which conditions there will be required a 175-h.p. engine and producer, and in addi-

TABLE XXXIII. GAS PRODUCER PLANT

INVESTMENT	
Engine and producer (A)	$11,900
Generator, switchboard, wiring (B)	2,500
Building (C)	2,500
	$16,900
FIXED COST	
Interest, 6% on $16,900	$1,014.00
Profit, 5% on $16,900	845.00
Insurance and taxes, 2% on $16,900	338.00
Amortization on A, 15-yr. life, 4½%	535.00
Amortization on B, 20-yr. life, 3%	75.00
Amortization on C, 50-yr. life, ½%	12.50
	$2,819.50
OPERATING COST	
240,000 kw.-hr.	
Coal, 3 lb. per kw.-hr. at $4.00 per ton, 360 tons	$1,440.00
Engineer at $18.00 per week	936.00
Oil and waste	125.00
Repairs	300.00
Water	133.00
Emergency service	300.00
	$3,234.00
Total	$6,053.50
Cost per kw.-hr.	0.025
Cost per hp.-yr.	56.20

tion a heating plant for heating the building, but as the heating plant is required in any event the cost of heating is eliminated as a comparative factor in the problem. The investment, fixed costs and operating costs of this plant are given in Table XXXIII.

This gives a higher fixed cost than for the steam plant, while the operating costs are only about .5 that of the steam plant, but are counterbalanced by the cost of heating. The final result gives a slightly higher cost for the gas-producer plant. The ratio of the fixed cost to operating cost in the two cases produces a marked effect where the load factor is poor. The only items affected by the output of the plant are coal and water, these representing only about 27% of the total cost, as against 50% with the steam plant, the result being a very much higher cost for the gas producer at low load factors, which effect would be further exaggerated by the poor fuel economy on light loads.

Cost of Power in Coal Mines. W. A. Thomas in the proceedings of the A. I. E. E. for January 9, 1912, gives the following figures as the result of careful tests on 4 typical plants in Ohio in which the average capacity was 250 kws. per station.

Average cost of power	2.485 ct per kw-hr.
Cost for substation equipment, less salvage	.124 " " " "
Common cost for either source	.7 " " " "
Central station rate to balance against present cost	1.661 " " " "
Average power consumption	47,700 kw.-hr.
Average kw.-hr. per ton coal	2.49

An analysis of several typical small mining plants shows that the average working days per month to be from 15 to 20, and the average load factor during an 8-hr. day to be slightly over 50%, based on a ratio of average consumption to maximum duration, not taking into account the actual capacity of the generators or the momentary swing of the ammeter.

Heating and Power Costs in New York City Isolated Plants. Percival R. Moses gave the following figures, Proc. of the A. I. E. E., January 12, 1912.

COST OF FUEL AND LABOR FOR HEATING IN TYPICAL BUILDINGS WITHOUT PRIVATE ELECTRIC PLANTS

APARTMENT HOUSES

100 by 100 ft. 7 stories and basement — 21 apartments — one elevator. Steam for heating and hot water and pump. Fuel used No. 1 buckwheat at $3.25 per ton	Fuel $1150 to $1250 Labor $1200 to $1320
200 by 100 ft. irregular — 8 stories and basement — 72 apartments — two elevators. Steam for heating and hot water, laundry dryers and pumping. Fuel used costs $2.05 per ton	Fuel $2350 Labor $2276
200 by 92 ft.— 11 stories and basement — block front — 77 apartments — elevators. Steam for heating and hot water. Coal for heating. Coal for hot water amounted to 300 tons in a year. Stoves for dryers. Fuel used, pea coal	Fuel $4317 Labor $2800

(Corner) — 100 by 100 ft.— 12 stories.
Steam for heating, hot water dryers, refrigerating plant and pump. Used 1050 tons No. 1 buckwheat .... Fuel $3700
Labor $2465

HOTELS

Apartment hotel. 50 by 100 ft. 10 stories .... Fuel $2700
Labor 1920

High class apartment hotel. 50 by 100 ft., and annex 25 by 100 ft.— 4 stories.
Heating hot water and refrigeration. Absorption system. Low pressure steam .... Fuel $2503
Labor $1920

OFFICE BUILDINGS

12 stories — corner building.
Corner heating and some hot water .... Fuel $1700
Labor $2500

Corner — office — 11 stories — 86 by 150 ft.
Heating, steam for kitchen and refrigerating plant.
Steam for hot water (25 h.p. and up) .... Fuel $3564.65
Labor $3746.25

50 and 30 by 197 ft.
12 stories — protected on west .... Fuel $1047.50
Labor $2020.00

$3067.50

Offices.
Steam for heating. Plunger elevators. Pumping and hot water .... Fuel $4383.35
Labor $5798.52

$10,181.87

Offices 45 by 85 ft.— 16 stories — corner — three electric elevators .... Fuel $1,180
Labor $ 810

$1,990

Loft building — 50 by 100 ft.— 12 stories, middle of block protected. .... Fuel $800
Labor $420

100 by 100 ft.— Salesrooms — 12 stories. (Corner). Fuel $1,580
Labor $5,798

128 by 90 ft. and 173 by 90 ft. (52.7 by 27 m.) — Mail order house — 11 stories and basement.
Steam for heating hot water. 4 plunger elevator pumps and house pumps .... Fuel $4,621
Labor $4,100

75 by 185 ft.— 12 stories and basement — middle of block but exposed above lower floors .... Fuel $1,280
Labor $713

10 stories — 123 by 143 ft. (Corner) .... Fuel $2700
Labor $ 960

DEPARTMENT STORES

207 by 100 ft. and 25 by 104 ft. and 99 by 75 ft.
Steam for heating refrigerating and pumps and hot water. Hydraulic elevators. 7000 kw.-hrs. ... Fuel $6,583
Labor 6,084

92 by 122 ft. and 253 by 184 ft.— 7 and 10 stories; yard (anthracite) screenings and soft coal .... Fuel $5,967
Labor 5,000

23,000 sq. ft.— seven stories — six passenger and three freight elevators (plunger type). No. 1 buckwheat anthracite .... Fuel $4,000
Labor 5,000

200 by 200 ft.—6 stories and basement. Use No. 2 buckwheat coal	Fuel	$6,231
	Labor	4,056
Factory and loft building—two buildings about 12,000 sq. ft. per floor—6 stories and basement	Fuel	$1,100
	Labor	936

Mr. Moses says the figures given opposite the labor for each building are within 10% of the actual payroll.

Cost of Power in a Large Apartment House. Table XXXIV, showing the operating charges of the plant of The Spencer Arms Apartments for the years 1910 and 1911, was made up from data in the September, 1912, issue of The Isolated Plant.

The building is 160 by 112 ft., 12 stories high, each floor containing 3 apartments. The service demanded of the plant consists of electricity for public and private lighting, electric power for 4 elevators, steam for heating the building and for laundry use; also, refrigeration, which is supplied direct to each apartment ice box by brine circulation.

The principal features of the plant equipment are:

3 horizontal return tubular boilers of 150 b.h.p. each.

3 direct-connected generators of 65 kw. capacity each.

1 refrigerating machine of the compression type of 12 tons capacity.

The basic cost as shown is the cost of operating the plant without producing electricity.

TABLE XXXIV. MONTHLY COST OF OPERATION, SPENCER ARMS APARTMENTS

	Jan.–Dec., 1910			Jan.–Dec., 1911		
Plant output,	Min.	Av.	Max.	Min.	Av.	Max.
kw.-hrs.	7,672	14,834	18,780	7,980	15,568	21,620
Total cost	$1,063	$1,321	$1,679	$1,075	$1,248	$1,373
Basic cost	$710	$922	$1,154	$770	$871	$1,052
Cost of electricity	$294	$399	$631	$269	$377	$488
Cost per kw.-hr.	$0.0197	$0.0269	$0.0389	$0.0141	$0.0243	$0.0490
Fuel	$329	$514	$834	$330	$483	$604
Engine room labor	$447	$450	$453	$450	$461	$496
Water (estimated)	$43	$136	$165	$67	$115	$147
Oil	$18	$28	$38	$22	$31	$42
Engine room sundries	0	$8	$30	0	$10	$35
Ash removal	$40	$40	$40	$40	$40	$40
Improvements and new installation	0	$8	$37	0	$12	$109
Long time supplies	$2	$24	$85	0	$28	$85
Extra repairs	0	$6	$40	0	$3	$16
Repairs to plant	0	$49	$169	0	$89	$476
Building repairs	0	$7	$35	0	$4	$19
Elevator repairs	0	$15	$61	0	$31	$157
Fuel used	No. 1 Buckwheat			Nos. 1 & 2 Buckwheat		
Tons fuel used	105	167	249	111	151	202

Cost of Power, Light, and Heat, from Steam for 19 Buildings. The following data for the operation of the Eberhard Faber Pencil Company's Plant were published in the July, 1912, issue of The Isolated Plant. This is a factory plant generating power, light and

heat for 19 buildings, with a total floor area of 241,200 sq. ft. and a cubical content of 2,432,700 ft. and with 22,000 sq. ft. of heating surface. The buildings have 3 elevators, 2 electric drum and 1 electric traction type, with capacities of 1,000, 3,000 and 4,000 lbs.

The plant consists of 1 Corliss engine, direct-connected to a 2-wire, 240-volt d.c. dynamo of 350 kw. capacity. There are 4 water-tube boilers of 1,100 rated h p. Heating is done by 2-pipe system, gravity type. The auxiliary apparatus comprises 1 feed water heater of the open type and of 600 h.p. capacity, 1 duplex pump 6 by 4.5 by 10 ins., one 6 by 4 by 7 ins. and 1 10 by 8 by 10 ins.

Electricity is used by 30 arc lamps, 100 Mazda and 1,200 carbon lamps, and there is a total of 600 motor h.p. in use in addition to the power required for running blowers, fans and other accessories.

The approximate cost of the engines and dynamos with their foundations, switchboard and connections required by private electric plant was $16,600. The approximate cost of all other material, such as boilers, feed water heater, pumps, etc., was $10,400.

The fuel used is No. 1 buckwheat, costing $3.25 a ton.

The following are the fixed charges and operating cost for the year 1911:

Interest on $27,000 at 6%	$ 1,620
Depreciation on $27,000 at 5%	1,350
Rent	1,000
Insurance	75
Fuel	3,954
Labor	3,780
Ashes	314
Water	400
Repairs	400
Oil and sundries	360
Lamps	150
	$13,403
Saving due to exhaust steam heating	1,511
	$11,892

The kw.-hr. output for the year was 774,005, and the cost, $\frac{\$11,892}{774,005}$, = 1.53 cts. per kw.-hr.

In these fixed charges and operating cost for the year 1911, the fuel, ash and labor items represent 52.5% of the total operating expense. Water, oil, lamps and repairs represent the total and must be charged to power and light. The water used by engine and pumps was 52.5% of the total water evaporated. This water goes to waste in the summer. The engine runs condensing and in the winter, after the exhaust steam goes through the heating coils, the returns and condensation all go to the sewer. The other 47.5% of the steam is used for manufacturing purposes and condensation from this is always returned to the boiler.

Operating Records of a Large Loft Building. The following operating costs, prepared by S. Milton Clark, were abstracted from the August, 1912, issue of The Isolated Plant:

In the heart of the wholesale feather and dry goods district in lower New York is located the large loft building known as the 580 Broadway building. It has a frontage on Broadway and Crosby Street of 150 ft. and 200 ft., respectively, and is 12 stories high.

The cost of the electrical output from this plant averages $0.0234 per kw.-hr.

The plant equipment is as follows: 3 horizontal return tubular boilers, with total capacity of 375 h.p.; 4 high speed engines direct connected to d.c. generators, 1 of 75 kw. and 3 of 100 kw. capacity each.

The summary of operating expenses is shown in Table XXXV, and special attention is called to the "Basic Cost." This item is the amount it would require for heating, furnishing live steam to tenants, care of elevators, etc., without the electric plant, and the amount was obtained from the cost previous to the installation of the plant.

If the 405,020 kw.-hrs. generated in 1911 had been purchased from the street at the present wholesale rates, it would have cost $15,150.60. The cost from the plant was $9,448.02. The saving affected by the plant was $5,702.58.

TABLE XXXV. MONTHLY COST OF OPERATION, LOFT BUILDING

	Jan.–Dec., 1911		
	Min.	Av.	Max.
Output, kw.-hrs.	24,490	33,752	46,490
Total cost	$1,324	$1,571	$2,208
Basic cost	$650	$783	$950
Cost of electricity	$545	$787	$1,458
Cost per kw.-hr.	$0.0162	$0.0234	$0.0395
Fuel	$416	$577	$725
Engine room labor	$790	$811	$844
Water (estimated)	$15	$30	$41
Oil	$14	$33	$52
Engine room sundries	0	$21	$73
Improvements and new installations	0	$6	$37
Long time supplies	0	$23	$52
Repairs to plant	0	$80	$595
Discounts	$2	$9	$24
Receipts from tenants	$589	$909	$1,464
Kind of fuel used	Buckwheat and soft		
Tons fuel used	144	195	258

Power and Maintenance Costs of 12 Story Loft Building. The following data are also from Isolated Plant. The building covers a plot 100 by 100 ft., and is 12 stories high. Three floors are given up to printers and the others are occupied by manufacturers and wholesale supply companies.

When the building was first erected, the electricity to operate its light and power apparatus was furnished by the "Blank" Company, but 2 100-h.p. high pressure boilers were put in for heating purposes with the view of operating a power plant should it seem advisable.

Current is used to run 4 Otis electric elevators — 2 passenger and 2 freight; 30 motors ranging from 0.5 to 30 h.p., 1,000 incandescent electric lights and 20 arcs and to operate motor driving a triplex

pump which supplies a 14,000 gal. tank on roof. Also, an electrically driven air compressor for pressure tanks as emergency for fire system.

In 1908, the following generating equipment was installed in the basement: One Fishkill Corliss Engine, belt connected to a C. & C. generator of 125 kw., 240 volts capacity; also, a 17.5 kw., 125 volts C. & C. motor driven balancer set. Forced draught was also provided in order to keep steam up to required pressure.

Table XXXVI shows the operating cost of this plant, the total amount, $7,757, including heat, light, power and maintenance charges.

TABLE XXXVI. MONTHLY COST OF OPERATING LOFT BUILDING

	April, 1909 to March, 1910		
	Min.	Av	Max.
Fuel	$178	$251	$343
Labor	$240	$243	$254
Water	$29	$39	$63
Sundries	0	$5	$20
Oil	$15	$23	$59
Repairs and new installations	$27	$68	$93
Heat and maintenance of building	$300	$300	$300
Light, kw.-hrs.	1,840	4,097	6,370
Power, kw.-hrs.	7,490	10,188	12,950
Cost of current, wholesale rate	$467	$683	$903
Total engine room expenses			$7,757
Less heat and maintenance of building			3,600
			$4,157
Total kw.-hrs.			171,420
Cost per kw.-hr.			$0.0242
Wholesale cost of current			$8,199
Cost of private plant electricity			$4,157
Saving, private plant			$4,042

Cost of Power for a Large Semi-Public Building at Kansas City, Mo., as Compared with Cost if Purchased from the Central Station. The following data are from Isolated Plant, May, 1913.

For erection of part of building occupied by plant, figured at 25 cts. per cu. ft.	$5,250
Engines and generators	4,800
Boilers	2,350
Boiler settings	796
Pumps	152
Switchboard	1,860
Ice machine and freezing tank	1,400
Feed-water heater	255
Oil burning system	850
Return pump and tank	127
Pipe work and installation	2,500
Total investment	$20,340

Cost of Service if Purchased from Central Station:

Light, 123,704 kws. at 3.5 cts.	$4,329.64
Power. 31,824 kws. at 3 cts.	954.00
Refrigeration, 1.2 tons per day at $2.70 a ton	1,182.00

Ice, 250 lbs. per day (313 days only) at 22 cts.		172.15
Lamps		144.00
Salary of engineer to care for elevators, plumbing, steam fitting laundry machinery, electric wiring, etc., at $85 per mo.		1,020.00
Extra help for engineer at $15 per mo.		180.00
Heat for winter season, 6 mos.		
Average live steam per hr.	2,069 lbs.	
Average live steam per day	49,656 lbs.	
Cost per day at 45 cts. per 1,000 lbs.	$22.34	
Cost per season of 182 days		4,065.88
Water heating for winter season		
187,500 lbs. per day from 50 to 100 degs. F., 9,375,000 heat units per day.		
9,375,000 heat units, condensation of 9,705 lbs. steam from and at 212 degs. F.		
Cost of 9,705 lbs. steam at 45 cts. per 1,000 lbs.	$4.36	
Cost per season of 182 days at $4.46		783.52
Water heating for summer season		
187,500 lbs. per day from 70 to 100 degs. F., 5,765,000 heat units per day.		
5,765,000 heat units per day, condensation of 5,967 lbs. steam from and at 212.		
5,967 lbs. steam costing 45 cts. per 1,000 lbs. at $2.68 per day.		
Cost for season, 182 days, at $2.68 per day		487.76
Total cost		$13,318.95

Actual Cost of Heat, Light, Power and Engineer's Services:

Labor	$2,360.00
Fuel oil	4,488.00
Water	90.00
Oil, waste and supplies	100.00
Boiler compound	180.00
Insurance	25.00
Lamps	144.00
Total paid out	$7,387.00
Cost, if purchased from central station	$13,318.95
Actual cost	7,387.00
	$5,931.95
Depreciation on equipment	$754.52
Interest on entire investment at 5%	1,017.02
	$1,771.54
Cash paid out	7,387.00
Total (including depreciation and interest on total investment)	$9,158.54
Cost, if purchased from central station	$13,318.95
Total, including depreciation and interest	9,158.54
Net saving	$4,160.41

A Comparison of Efficiencies and Costs of Steam, Water, Gas and Oil Power Generation. A study of power costs and efficiencies which is particularly valuable to the non-expert reader because of its simple language is contained in the Report of the Maine State Water Storage Commission. This discussion is by Seth A. Moulton of Sawyer & Moulton, consulting engineers, Portland, Me., and is

based on the extensive practice of the writer in water power development and power plant design. The following are parts of the report which are of general interest, abstracted by Engineering and Contracting, Sept. 4, 1912.

There are commercially available four distinct classes of power, steam, water, gas and oil, naming them in the order of their prestige.

Efficiency defined in its broadest sense means not only the most complete utilization of the elements converted but also the most economical combination of appliances and labor to effect the conversion. To secure in power generation a maximum efficiency and economy does not imply that the last vestige of available energy must be extracted from the fuel or water element, with the unwarranted refinements of equipment and attention which such an impractical course would impose; or that the other extreme should

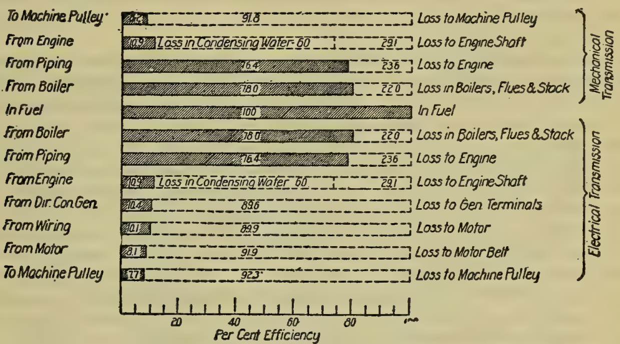


Fig. 38. Power efficiencies — steam.

be applied by using the cheapest apparatus and labor procurable in a vain attempt to economize; but it is necessary to carefully balance all of the factors involved, endeavoring always to deliver to the point of final application a maximum amount of the energy originally expended at a minimum cost.

Physical Efficiency. Figures 38 to 41 inclusive show graphically the efficiencies which may be expected to obtain in the practical running of steam, producer gas, oil and water power plants, with first-class installations, supplying a service where a fairly constant loading exists and when operated by competent mechanics. It is true that the average power plant does not attain the heat efficiencies indicated on the diagrams, but they are well within results which have been excelled in a few plants and can be usually obtained in plants of 1,000 h.p. or more capacity.

Fig. 38 shows the thermal efficiency obtained at the several stages of transportation in a steam plant from the 100% of heat value in the fuel, as placed under the boilers to the mechanical energy de-

livered to the machines. The plottings on the diagram above the fuel line are for mechanical transmission and those below for local electrical distribution. To secure the operating economies indicated the plant must be equal to or in excess of 1,000 h.p. capacity. For smaller plants the efficiencies would be less, probably falling as low as 5 or 6% of the theoretical energy in the fuel when delivered as mechanical energy to the machine or other point of use. It is also improbable that these efficiencies can be realized in central stations that distribute power for all classes of service, owing to the fluctuations of the demand. The average load in these stations does not ordinarily exceed 30% of the power required to maintain the maximum, or so-called "peak" load, which will exist only for a short period during each day. It is also very difficult to maintain the high boiler efficiency of 78%, as this requires constant cleaning and very careful operation, with the application of the most scientific methods for the manipulation of drafts and firing of the boilers. The average boiler efficiency will probably not exceed 75% in plants of the better class.

Up to the engines all of the losses are thermal; at the engines the losses are both mechanical and thermal, and a general inspection of the diagram would indicate that the steam turbine or engine is a very inefficient mechanism, as the total heat and mechanical efficiency drops from 76.4% to only 10.9%. This is not true, however, for it must be remembered that the 60% noted on the diagram as lost in the condensing water should not be charged against the engine, as the heat energy so expended is latent or liquid heat, for the exhaust steam from an engine has practically the same pressure as the medium into which it is discharged and the temperature of the steam is controlled by this pressure. It is obvious that there will be no available potential energy from such exhaust steam, as this energy is neutralized by the opposing back pressure which may be either above, below or equal to the atmospheric pressure, depending upon the conditions at the exhaust outlet; but under all circumstances the full heat value of the steam remains unimpaired. Crediting the engine with this 60% by deducting it from the 76.4% (the thermal efficiency delivered from the piping) leaves 16.4% of heat energy actually delivered to the engine which may be converted into mechanical power; then the combined efficiency of the engine and its auxiliaries becomes $(10.9\% \div 16.4\%) \times 100 = 66\%$. An appreciation of this condition is most essential because it explains why the steam can never compete in heat efficiency with the internal combustion engine, either gas or oil. This condition is also of paramount importance when selecting the type of apparatus or determining the character of the power to adopt for an industry that requires heat for manufacturing or process purposes. Referring to Fig. 38 it will be noted that 76.4% of the heat in the fuel is admitted to the engine throttle and that only 10.9% of the total heat in the fuel is converted to mechanical power; therefore, the waste heat rejected by the engine exhaust is 65.5% of the total in the fuel, and there remains in the exhaust steam $65.5\% \div 76.4\%$, or 85% of the heat that was delivered to the engine. It is conservative to state that there is available for process purposes at least 75% of

the heat value in steam after all available potential energy has been extracted from it, and maximum economy demands that this heat should be used as heat if possible, rather than dissipate it in the cooling water of a condenser to secure the comparatively small percentage of mechanical energy thus acquired.

To indicate the gain secured by utilizing exhaust steam for heating purposes, Table XXXVII is given:

TABLE XXXVII

% of exhaust steam used for heating purposes	Lbs. of coal per h.p. per hr. All coal charged to power	Net lbs. of coal per h.p. per hr. after deducting for exhaust steam used
0	1.75	1.75
25	2.06	1.50
50	2.38	1.25
75	2.69	1.00
100	3.00	0.75

This table was compiled by Charles T. Main, a prominent civil engineer, who has long advocated and made practical application of engine exhaust for industrial heating purposes.

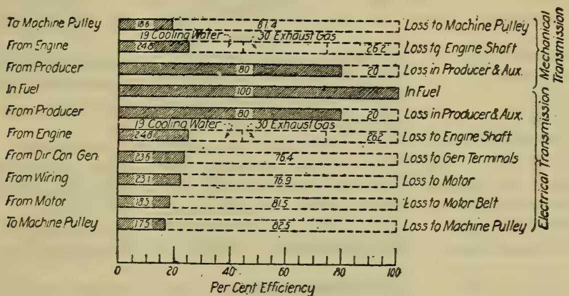


Fig. 39. Power efficiencies — producer gas.

Where all or a greater part of the exhaust can be utilized, simple non-condensing engines or turbines should be installed, and where lesser amounts, down to 25% of the steam required for power purposes, the exhaust can be taken from the "bleeder turbines" or the intermediate receivers between the cylinders of a compound engine, operating either non-condensing or condensing, whichever proves the most economical.

Fig. 39 illustrates the efficiency of producer gas plants in the same general manner as that previously described for steam. The great advantage of the gas equipment lies in the fact that for all plant capacities there can be maintained practically the same efficiencies, making the smaller producer gas plant proportionately more efficient than the steam. In addition, cheap grades of fuel can be

efficiently used in a gas producer which could not be burned with any degree of economy under a boiler, and the higher grades of fuel can be more efficiently used in a producer than in a boiler.

What has been said in regard to the producer gas plant applies generally to the efficiency of oil engines, with the exception that such

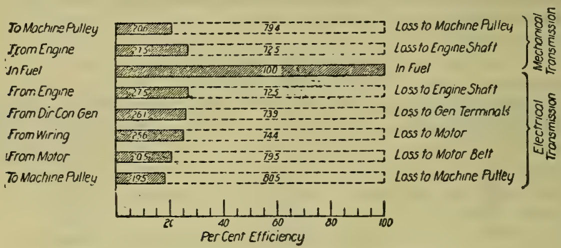


Fig. 40. Power efficiencies — oil.

an equipment is still more efficient than the gas, as is shown on Fig. 40.

Figure 41, illustrating the efficiency of hydraulic or hydro-electric power plants, is self explanatory. It shows more stages than the

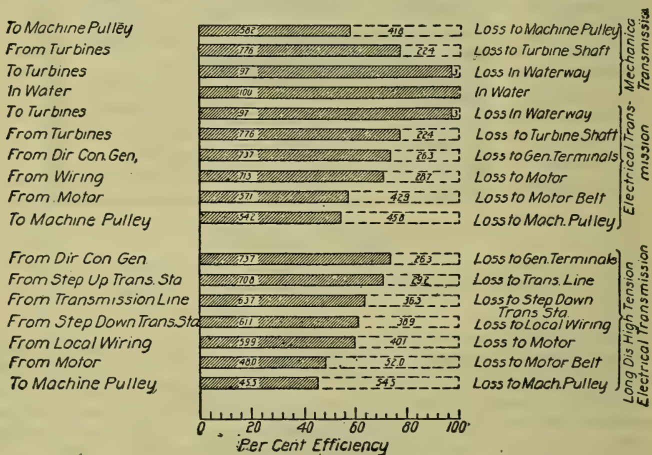


Fig. 41. Power efficiencies — water.

foregoing plates, because it includes long distance electrical transmission, as given on the lower sections of the diagram. If desired, this diagram can be used to obtain the losses or the net efficiency for long distance transmission in connection with any of the previously described diagrams.

Figure 42 forcibly depicts the superior efficiency of water power, indicating that it is 604% more efficient than steam power at its best, 209% more efficient than producer gas power and 178% more efficient than oil power. In addition, nature continually replenishes the "white coal" for the water power, while man constantly depletes nature's storehouses to supply the fuel for the other classes.

Although the comparisons indicated by this last diagram are startling and would make it appear that water power had an almost immeasurable value, it must be remembered that the cost of installation is in most instances large and that the water supply must be utilized as it is afforded by nature, unless storage reservoirs are provided of ample capacity to impound the freshets at situations on the stream or river where a maximum amount of the runoff from a given watershed can be retained, with ample pondage facili-

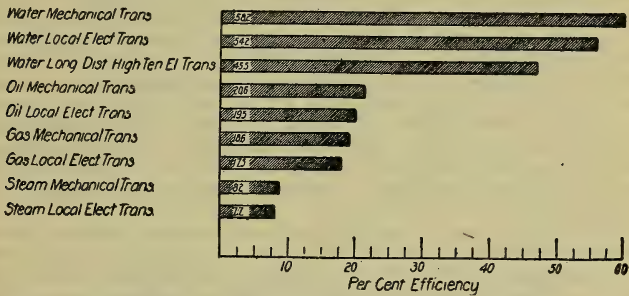


Fig. 42. Comparative efficiencies of various sources of power.

ties at the plant to regulate daily fluctuations. All these facts tend to increase the cost of hydraulic power and decrease the value of power sites, except in sections especially favored by nature, remote from a fuel supply, where a demand exists for a volume of high grade power within reasonable transmission range.

Investment Efficiency. All of the diagrams previously described show only what may be termed the "physical efficiency" of the several plants; but there is another factor of greater importance, as indicated by the above statement in regard to the cost of water power, this has been called "investment efficiency." Physical efficiency applies only to the utilization of the elemental factors, investment efficiency considers the cost necessary to control and apply these elements; and the ideal power to be selected for a given situation will be that which shows the greatest economy when both the "physical" and "investment" efficiencies are maximum.

The "investment efficiency" has no definite base for unity, such as the heat value of a fuel or the potential energy of water, but is obtained by determining the ratio between one or more known capitalized costs; the "capitalized cost" being the capital invested in the project plus the sum obtained by capitalizing the total annual expenditures at the rate of interest allowed on the capital invested.

To illustrate: A steam power plant costs \$100,000 and the rate of interest is 5%. The annual expenditure to operate this plant is \$50,000; then the "capitalized cost" will be \$100,000 + (\$50,000 ÷ 0.05), or \$100,000 + \$1,000,000 = \$1,100,000. A hydraulic plant to supply the same service costs \$150,000 and the annual operating expense is \$20,000. At the same rate of interest previously allowed, the "capitalized cost" will be \$150,000 × (\$20,000 ÷ 0.05) = \$550,000. The "capitalized cost" of the steam plant is \$550,000 more than that for the hydraulic installation, and calling the hydraulic plant capitalization unity the steam plant has a 50% "investment efficiency."

The above method is the simplest way to determine the best investment, and it can be proved to be accurate by making a more detailed analysis. For example: Each of the above plants has a rated capacity of 1,800 h.p. and delivers annually 6,000,000 h.p. hrs.; then the expenditure per h.p. hr. for the steam plant will be \$50,000 ÷ 6,000,000 = \$0.00833, or 8⅓ mills, and the interest charges, \$100,000 × (0.05 ÷ 6,000,000) = \$0.0008, making the total cost per h.p. hr. \$0.00913. For the hydraulic plant the expenditure per h.p. hr. will be \$20,000 ÷ 6,000,000 = \$0.00333, or 3⅓ mills, and the interest charges, \$150,000 × (0.05 ÷ 6,000,000) = \$.00124, making the total cost per h.p. hr. \$0.00333 + \$0.00124 = \$0.00457. From the above it will be seen that the steam power costs twice as much as the hydraulic, and, accordingly, it has an "investment efficiency" of only 50%.

The manufacturer of power equipment usually presents to the prospective purchaser the economies of his apparatus viewed from the standpoint of "physical efficiency," claiming that this is the most important factor to consider in securing low cost power. The central station managers purport to fix their charges for power below the apparent cost of other forms of power, and they are disposed to exaggerate the cost of such power, placing particular emphasis on the "investment efficiency," in order that they may secure a maximum return for their commodity. The consulting engineer is constantly confronted with inaccurate statements in regard to the cost of power that are devised to convey erroneous impressions, either through intent or otherwise, with every advantage taken of bookkeeping ambiguities. In this manner reports are circulated that are incomplete or compiled with the specific purpose of misleading, and it is almost impossible to dispel these influences and convince a client that the advanced claims cannot be substantiated in actual practice. The greatest discrepancies are encountered in the figures given for the cost of steam power, and within certain limits this is to be anticipated, on account of the many controlling factors later enumerated; but with a fair comprehension of the premises any competent engineer should be able to analyze given conditions and compile an estimate which will be sufficiently accurate for all practical purposes. Should two reliable engineers report on the same project, it is likely that their figures for the cost of power would not vary more than 5% and probably less, if the general conditions governing the layout were sufficiently

well defined by the local surroundings to occasion the presentation of two similar designs. We do not mean by the above statement that the estimated cost of the installations would necessarily be within 5%, but that the cost for *a unit of power for a given period of time* would be within these limits.

An engine salesman blandly informs the prospective purchaser that he can furnish an engine which will generate 1 h.p., meaning indicated h.p., using only 16 lbs. of steam per hr., and that with reasonably efficient boilers this would mean about 1.75 lbs. of coal per hr. per h.p. The central station representative disputes this claim, stating that it will require at least 23 lbs. of steam, or 2.5 lbs.

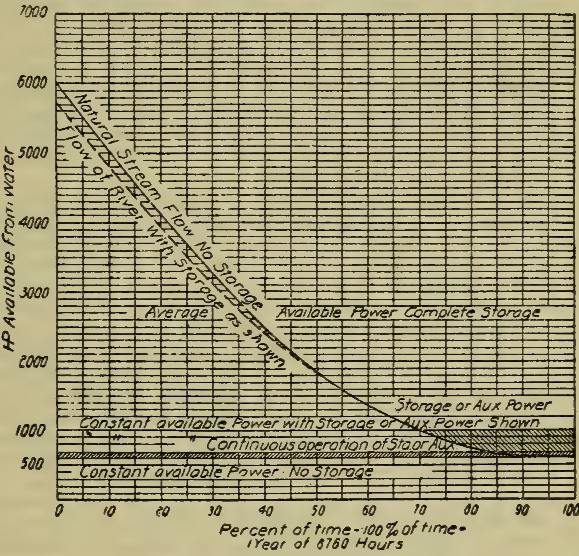


Fig. 43. Effect of storage and auxiliary power.

of coal per hr. per h.p. The latter had considered the mechanical losses in the engine, the losses in the auxiliaries, the generator losses, the wiring losses and the motor losses, figuring on the power delivered to the line shafting or machines where it was to be utilized. Somewhat disturbed, the victim seeks the advice of a specialist, only to learn that both statements are correct. Then confusion becomes chaos and a task is set for the counselor if he tries to convince his client that each adviser has told him nothing but the truth, although both have deceived him.

The prospective purchaser of power or power equipment will naturally question the reliability of information received from either

equipment manufacturers or the central station agents, as he appreciates that the opinions advanced may be biased; accordingly, the influence of inaccurate statements from these sources is somewhat restricted; but when a company, generating power for its own use, becomes imbued with the idea that it has succeeded, by some special dispensation, in overthrowing the laws which regulate costs and thus has accomplished results that have not and cannot be attained, it is almost impossible to refute such statements or to convince the self-deceived party as to the error of its ways, and prevent the conversion of others into an acceptance of the false theories. Admitting the difficulties encountered in endeavoring to secure records and accurate information in regard to the cost of power, due to the many variables that affect such costs, it is absurd to assume that it is impossible to compute or predetermine with reasonable accuracy the cost of power for a given service or to claim that the secret of efficient and economical power generation is the special knowledge of an esoteric few. What has been once accomplished can be repeated; yet from the evidence which has been placed before us purporting to be accurate records of power costs, this logic seems to be refuted.

Much of the difficulty encountered in refuting inaccurate costs can be attributed to a confusion of the technical terms used in connection with power measurement and a lack of understanding in regard to the units of power measurement. In most instances the difficulty of comparison would be removed if the point of power measurement was clearly defined. It has been an almost universal custom to compute and compare power costs on the basis of 1 h.p. per yr., using the term "cost per horsepower year," an absolutely meaningless expression having no significance unless it be specifically defined by the number of hours' operation per year, the point of measuring the power and whether or not it be indicated, brake or electric horsepower, and if transmitted electric power whether it is metered on the high or low tension side of the consumers' transformers. The only true unit for the measurement of power or for comparison of cost is the kilowatt or horse-power hour, then it does not matter what the hours of the service may be, for at the same point of delivery any class of power can be compared without confusion or conveying false impressions.

In view of the above noted conditions, the following definitions are inserted:

Indicated Horsepower; Notation: i.h.p.— This is the power generated in the cylinder, or cylinders, of a reciprocating or rotating engine and is the measure of the energy exerted by the steam or gas as determined by an indicating mechanism which does not record the mechanical or friction loss in the engine itself.

Brake Horsepower; Notation: b.h.p.— This is the mechanical energy delivered by an engine, waterwheel, motor or at any other mechanical appliance, as determined by applying a friction brake or electrical resistance, thus weighing the power. For an engine the b.h.p. will be the i.h.p. minus the losses in the engine itself, and the h.h.p. is usually from 90 to 95% of the i.h.p.

Electrical Horsepower; Notation: e.h.p.— This is the power in the electric current which is delivered at the terminals of the electric generator, at the switchboard or at the motors, and is the b.h.p. minus the mechanical and electrical losses in the generator; or, if delivered to the motors, the above losses plus the losses in the wiring. For electric generators the efficiencies will be from 90 to 96% of the b.h.p. of the driving element, if the generator is directly connected to the prime mover without intervening belts or gearing.

Horsepower Hours; Notation: h.p.-hrs.— This is the number of horsepowers utilized in one hour, or the numbers of hours during which one horsepower is utilized. To illustrate: — A plant operates for 300 days of 10 hours each, or for a total of 3,000 hours, and generates continuously during this period 10 horsepower. This is equal to $10 \times 3{,}000$, or 30,000 h.p.-hrs. Another plant operates for 1 day of 10 hours, or a total of 10 hours, and generates continuously during this period 3,000 h.p.; then $3{,}000 \times 10 = 30{,}000$ h.p.-hrs.

Kilowatt Hours; Notation: kw.-hrs.— Same as above, multiplied by the decimal 0.746. In other words, .75 of 1 kw. is approximately equal to 1 h.p. or 1 kw. equals 1⅓ h.p.

Rated Capacity; Notation; r. c.— The term rated capacity as herein used is the maximum normal capacity of the plant equipment, expressed as horsepower for the size of the plant, or as h.p.-hrs. for the load it will carry during a given period of time.

Nominal Capacity; Notation: n. c.— The nominal capacity of a plant is the output from the equipment when operating at its maximum efficiency, or with the load for which it was designed.

Capacity Factor; Notation: c. f.— This is the ratio between the total output of the plant if run at its "rated capacity" for 365 days of 24 hrs., or for 8,760 hrs. per yr., and the actual output of the plant in the same period. For example: — A plant with equipment to generate 100 h.p. "rated capacity" has sufficient capacity to deliver $8{,}760 \times 100 = 876{,}000$ h.p.-hrs. per yr., but it is in operation 300 days of 10 hrs. each per yr. with an average load of 80 h.p.; thus its total annual output is $300 \times 10 \times 80 = 240{,}000$ h.p.-hrs., and the "capacity factor" will be $(240{,}000 \div 876{,}000) \times 100 = 27.4\%$.

Load Factor; Notation: l. f.— This is the ratio between the average output of the station and the maximum, or "peak" load which is imposed upon it. For example: — In the foregoing plant mentioned under "Capacity Factor" there was an average load of 80 h.p., but it was designed to carry continuously a load of 100 h.p.; therefore, the l. f. is $(80 \div 100) \times 100 = 80\%$. The l. f. for central stations varies from 30 to 50%, seldom exceeding the latter figure in the best managed plants. For industrial plants the l. f. will vary from 60 to 90%, averaging at least 75% and seldom falling below 60%.

Power Factor; Notation: p. f.— This factor has no direct relation to the cost of power, except as it is an element which must be considered in selecting the generator and motor equipment for a given service. It is a condition peculiar to alternating current apparatus, very difficult to define intelligibly except to those familiar with the theory of alternating currents. The current in an alternating cir-

cuit may or may not be in phase (in step) with the electro-motive force, or the pressure which forces the current through the circuit. The volt is the unit of measure for the electro-motive force, and the ampere for the current. The amperage may either lead or fall behind the voltage. This condition is due to the magnetizing wattless (that is powerless) current required by alternating apparatus. It will be noted that this magnetizing current is powerless, and it, accordingly, does not appreciably affect the capacity of the prime mover; but it does have material effect upon the size of generator that is driven by the prime mover, as the wattless current causes heating in the generator, and therefore the greater this wattless current the larger will be the generator required.

The power factor is the ratio of the useful power in watts, as recorded by the wattmeter, to the apparent power in volt-amperes, determined by readings from the volt and ammeters.

(Hence if the kilovolt ampere, kva., capacity of generator is multiplied by the power factor, the product is the kilowatt, kw., capacity).

The power factor of a plant depends largely on the character of the motor installation, and to maintain a high p. f. it is important that the motors operate continuously at or near their full load capacity. If the average "load factor" of a mill is 60% of the maximum load, the motors should be installed with "nominal capacities" to carry this 60% load; but they should have "rated capacities" sufficient to temporarily withstand the overload which will be imposed when the l. f. becomes unity, or 100%; that is, motors had better be too small rather than too large. Conversely, the generator must have ample surplus capacity, in order to avoid overheating when delivering current to a system with a low average p. f.

The p. f. can never be more than 100%, but with an incandescent lamp, or non-inductive load, it can attain this figure. A good average p. f. for a motor installation is 80%; many plants do not exceed 75%, and 60% is considered a low p. f. (An ordinary power factor for electric generators is 85 to 90%.)

Cost Factors. The general factors which control the cost of power are the investment required, the fixed charges necessary to maintain the investment, the operating charges, the load factor and the capacity factor. These are sub-divided as follows:

Investment	Cost of equipment. Cost of buildings. Value of land.	Capacity factor.
Fixed charges	Interest. Taxes. Insurance. Renewals — (Sinking fund.)	
Operating charges	Repairs. Labor. Supplies. Fuel. Water.	Load factor.

Both the capacity and the load factors have important influence on the cost of power, as will be noted by referring to the definitions

previously given for these terms. The c. f. affects more specifically the investment and fixed charges, while the l. f. has more effect upon the operating charges.

In addition to the above, there are specific factors which affect water power and power transmitted electrically from central stations or water powers remote from the place of usage. These are as follows:

Water power:
- Water rental.
- Storage charges.

Transmitted power:
- Transmission charges:
  - Patrol of lines.
  - Repairs of lines.
- Distribution charges:
  - Sub-station operation, including labor, repairs and supplies.
  - Local line patrol and repairs.
- Overhead charges:
  - Management.
  - Clerical or office.

General Consideration. The prospective power user may have three means of securing the desired power. First, by purchasing power from a public service or other distributing company; second, if water power is available, by thus generating his own power; or third, by installing a fuel operated plant. Ofttimes he must select from two only of the above, and in many instances from the latter class only.

It is obviously impossible to give any general rules or even approximate average figures which will apply to the cost of a hydraulic installation, and, hence, the cost of the power generated thereby, as each project presents problems occasioned by the natural conditions which require special engineering study. The costs of hydraulic and hydro-electric developments constructed in the past have varied from $30 to $300 per h.p. of rated capacity, a range of 1,000%, and the cost per h.p.-hr. varies accordingly. In a few instances contracts have been made for the delivery of hydro-electric power at the switchboards in the generating stations for $9 per h.p.-yr. of 8,760 hrs., or for slightly more than one mill per h.p.-hr.; and a cost of 5 mills per h.p.-hr. for 8,760 hrs. can be considered a reasonable figure.

Fortunately the other commercial systems of power generation are not surrounded by any such uncertainties as exist in connection with hydraulic plants. Local conditions will have some effect on the cost of installation, such as unstable foundation materials, remoteness from base of supplies with insufficient transportation facilities, dearth or impurity of water for boiler feed, etc., and scarcity of competent labor; but such obstructions will occur only in isolated instances. The cost of fuel, water and labor for a given location is usually readily predetermined, and the cost of installation under

ordinary circumstances will very closely approach an average for a plant of given size.

The scope of this paper is limited to those power users who have the alternative of purchasing power from some commercial plant, or of generating their own power from fuel, and as an aid in determining which type of apparatus to adopt when fuel is to be employed.

It is impossible in this article to enter into the technical details of analysis whereby the accompanying data are secured; but the deductions herein recorded are all derived from the results of actual practice and not by theoretical computations. While this paper is abbreviated and does not include all of the data which it is proposed ultimately to issue in connection with this subject, it does contain the information that a mill owner or manufacturer might desire if he wished to determine with a reasonable degree of accuracy the approximate cost for a given class of power, in order to compare the same with any other class on which the price per h.p.-hr. is established.

It appears advisable to touch upon a few of the salient features pertaining to the design of power plants in general and particularly to mention the advantages and disadvantages of the different types of installations herein discussed.

There is a prevailing tendency towards the almost universal adoption of the electric drive by all industries of any magnitude; accordingly, all of the accompanying diagrams for cost of installation and labor are compiled on this basis. The convenience, cleanliness, flexibility and reliability of the electric drive, combined with its high efficiency, as noted on Figs. 38–41, fully justify its use. While the efficiencies given on the diagrams indicate that mechanical transmission is somewhat more efficient than electrical, it must be remembered that intermittent service, occasioning low load factor, the segregation of equipment and other practical conditions may be such that the electric drive may equal the mechanical drive, or perhaps excel it in efficiency.

The aim to be sought in designing any type of power plant is to secure as simple an arrangement of equipment and structures as can be obtained to produce the desired results without sacrificing efficiency, flexibility and reliability. To attain simplicity and economy of operation the equipment should consist of a few large units, the total power being so sub-divided by the apparatus employed that a maximum of working efficiency can be obtained under the conditions imposed by the load factor. The units should be selected with the intention of operating them continuously at their "normal capacity," so far as practicable with a "rated capacity" sufficient to accommodate the "peak" load without excessive overloading or falling off in efficiency.

The merits of water power are almost self-evident, the principal expense of operation being confined to the investment and fixed charges, as the labor cost is very small and there is no fuel bill. The disadvantages of water power are the high cost of development; restriction of application, due to limited radius of distribu-

tion; and last, but not least, the intermittent stream flow which exists on most rivers, causing fluctuations in the available power. In many instances the last condition can be ameliorated to a large extent for a comparatively small expenditure, if the magnitude of the river is sufficient to warrant the construction of storage reservoirs and the users on the stream are broad enough to combine forces for the attainment of a mutual benefit.

The value of storage is not well understood; if it were, much more active steps would be taken to derive the benefits which it affords. Properly controlled storage is utilized to augment the stream flow at periods of low water, and in most cases it keeps in operation equipment which would otherwise lie idle, or be partially operated only; therefore, the only cost required to utilize storage water is the reservoir charges.

One million cu. ft. of water falling 1 ft. will theoretically develop 62,500,000 ft.-lbs., or 1,894 h.p. for one minute, which is equivalent to 31.56 h.p.-hrs. If this water is used in a hydro-electric installation having efficiencies, as shown by Fig. 41, there would be delivered to the generator terminals, or the station switchboard, 31.56 $\times$ (73.7 $\div$ 100) = 23.26 h.p.-hrs. On the basis of 1 mill per h.p.-hr. (the lowest price for power within the writer's knowledge, as previously quoted), this amount of water would be worth 2⅓ cts. if used with a fall of 1 ft.

It can be proven easily that developed Maine water power is worth not less than 2 mills per e.h.p.-hr., or $17.52 per yr. of 8,760 hrs., and in most instances it is worth more than 3 mills, or $26.28 per yr. With the value of power at the latter figure and with storage basins costing not in excess of $125 per 1,000,000 cu. ft. of capacity, it will only be necessary to utilize the water on a head of 160 ft. to show a net return of at least 6% on the investment, in addition to an allowance of 3% for the cost of maintenance and operation; and in many cases it will be found commercially profitable to develop extensive storage on streams where the total utilized fall does not exceed 100 ft.

Next to storage in importance, if not of equal importance, is the securing of ample pondage at or near the hydraulic power station to compensate for the daily fluctuations of stream flow, in order that the full quantity of water which passes the plant during a given period may be used in varying quantities through the wheels to satisfy the irregular load factor, which is bound to exist, without permitting any of the water to be wasted over the dam, except in case of freshets. Certain industries, such as ground wood pulpmills and electrochemical works, are not dependent to any extent upon pondage, as the output can be varied to suit the water conditions; but all industries are directly benefited by storage, because the stored water is that which would have been wasted during the high water seasons.

The value of water power has been often overestimated, resulting in the consummation of developments that never could show a proper return on the investment. It has been, however, more often undervalued and unwisely abandoned or disregarded, particularly in

connection with those mills that require steam for the partial preparation of their product.

Probably the realization of the full benefits to be derived from water power is best secured when it is operated in conjunction with auxiliary power in some form; with steam power if there is a use for the exhaust, or when cheap fuel is available, and with gas or oil engines where fuel is high.

Auxiliary power bears a relation to water power similar to that occupied by the storage reservoir, for it not only provides power during the periods of low water, but it *increases the average amount of water power* that can be economically utilized *continuously.* This latter feature was not mentioned in connection with the foregoing comments on storage reservoirs, as at that time we were endeavoring to show only the value of the storage to existing or contemplated installations, without incurring any additional expense for increased plant capacity; but there is afforded by the creation of storage a still further power increase which is best illustrated by the diagram Fig. 43. This diagram shows the amount of h.p. that can be obtained from a typical river, with the natural stream flow arranged in order of its magnitude and not according to seasonal fluctuations. The vertical lines represent time, the total 100% being equal to the 8,760 hrs. in one yr. Any volume of power, as indicated by the figures on the lefthand margin of the diagram and the corresponding horizontal line, can be obtained for a period of time equivalent to that designated by the figures on the lower margin for all amounts below and to the left of the curve marked "natural stream flow."

For example: Following up the line 10 from the lower margin until it intersects the upper solid line curve, then reading the figures horizontally opposite on the left margin, shows that 5,000 h.p. can be secured for 10% of one yr., or during $0.10 \times 8{,}760 = 876$ hrs.; that is, there can be obtained a total of $876 \times 5{,}000 = 4{,}380{,}000$ h.p.-hrs. The total area of the diagram below the "stream flow" curve represents the total quantity of power which the water could develop in the year of 8,760 hrs.

The horizontal line marked "average available power, complete storage," cuts the above "stream flow" curve at the point where the area of the enclosed space above the horizontal line between the left margin and the full line curve is equal to the area of the space below the horizontal line confined between the "stream flow" curve and the right margin of the diagram, and, therefore, shows the average amount of power in the water if it could be distributed uniformly throughout the year, or for the 100% time period. This shows that the average power is 2,600 h.p., or 43.5% of the maximum 6,000 h.p.

The whole rectangle below the horizontal line at 600 h.p., which is the intersection of the flow curve with the 100% time factor line, shows the quantity of power that can be utilized continuously without the aid of storage or auxiliary power, and this is equal to only 23% of the average power available and but 10% of the maximum power. The area of the above rectangle represents graphically the

h.p.-hrs., amounting in total to $600 \times 8{,}760 = 5{,}256{,}000$ h.p.-hrs. per yr. Assume that a storage reservoir be constructed of sufficient capacity to impound the equivalent of 700,000 h.p.-hrs.; this amount, if uniformly distributed throughout the year, would make the total yield 5,956,000 h.p.-hrs., or would increase the available power 13.3%, making a total of 680 h.p.; but this is not the actual increase. The storage volume in terms of h.p.-hrs. can be represented on the diagram in two ways, either by placing a rectangular area equivalent to the quantity of h.p.-hrs. above the rectangle which indicates the constant power available or by plotting an irregular figure of the same area to the right and above the "stream flow" curve, the end on the 100% time line with the top a horizontal line meeting the "stream flow" curve. It will be noted that the horizontal boundary line of the storage area terminates on the "stream flow" curve at the point of intersection between it and the 70% time factor vertical, and that for the balance or for 70% of the time that the vertical distance from the base or zero power line to the power curve is always greater than that at the above point of intersection; hence, there will always be a sufficient volume of water from the natural stream flow to develop continuously in conjunction with the storage or auxiliary power the amount determined by the altitude of the power scale at the previously described point of intersection, or for 1,000 h.p., as shown on the diagram. If the horizontal boundary of the storage area be projected across the diagram, the area of that portion of the diagram below this line will represent the total number of h.p.-hrs. available. This area is $1{,}000 \times 8{,}760 = 8{,}760{,}000$ h.p.-hrs.; therefore, the reservoir actually has increased the available power from 5,256,000 to the above amount, or by 66.5% instead of 13.5%, as was shown by the uniform distribution of the conserved water employed for the previously given storage values. The existence of storage will alter the profile of the "stream flow" curve, increasing it at the minimum flow and decreasing it at the maximum, making it conform to the lower dotted curve shown on the diagram, the area between the two curves being equal to the area of the storage.

As previously stated, auxiliary power in any form has the same effect as storage on the available power, and by considering the 700,000 h.p.-hrs. on the diagram as derived from steam or other source, the annual output will be the same. The capacity of the auxiliary plant can be determined readily from the diagram, for the maximum altitude of the storage area as measured by the power scale indicates the greatest amount of power that will be required, and by finding the mean altitude of the storage area the average power is obtained; these are for the case under discussion, respectively 400 h.p. and $266 \times$ h.p.

STEAM BOILERS AND ENGINES

No attempt will be made to compare the relative merits of steam apparatus other than to state what modern engineering practice would indicate to be the best equipment to select for a given service. Both water tube and fire tube boilers have practically the same

efficiency when properly designed. Water tube boilers can be economically built for much larger unit capacities than the fire tube; hence, they occupy less space and afford a simplicity in general design which is desirable for large installations. They are also more immune from the danger of explosion than other types. As a unit the water tube boiler and setting is more complicated than the horizontal return tubular or vertical "Manning" type of boiler; accordingly, for a small plant the latter types are generally more economical, both to install and operate.

In most cases reciprocating steam engines will prove the most economical for small plants having from 1 to 3 units of not more than 500 h.p. each. For installations requiring units of from 500 to 2,000 h.p. capacity, it is debatable whether or not the reciprocating engine or steam turbine should be adopted. In case the electric drive is not readily applicable, it is safe to assume that the reciprocating engine is the best; but if the electric drive is applicable and particularly if the l. f. is such that the equipment cannot be consistently operated at or near its "nominal capacity," then the steam turbine is the natural selection, on account of its ability to operate on fractional or overloads without sustaining the efficiency losses incident to operating steam engines under similar conditions.

In addition to the advantage of working range afforded by the steam turbine, it occupies much less space than the reciprocating engine and with the present state of perfection it is a simpler machine. On the other hand, the condensing equipment for the turbine must be more refined than that provided for an engine, on account of the high vacuum which must be maintained if the turbine is operated efficiently. This condition incurs additional upkeep and operation expenses, as well as first cost.

For units of more than 2,000 h.p. capacity, the steam turbine will usually prove to be the most economical.

The cost per h.p. for turbine and engine equipments with generators will be approximately the same for the smaller sizes up to units of about 800 h.p. capacity; above this size the turbine will cost somewhat less than the engine, and as the unit size still further increases the proportionate cost will constantly change in favor of the turbine outfit.

GAS ENGINES

The gas engine has by no means received the recognition in this country which it deserves, while in Europe it has been accepted and utilized most successfully. The abundance of cheap high grade fuels available in what appeared until recently to be unlimited quantities has caused the consumer to be lethargic toward any attempt at economizing in its use. Further than this, to speak plainly, the American manufacturer, in spite of his boasted acumen, canny business deals and claims to progressiveness, is most loathe to adopt many of the so-called "new ideas" that have long since become ancient history to our more scientific competitors in both England and continental Europe.

Producers and gas engines are more efficient under working conditions than the corresponding steam equipment. Gas power plants require no high pressure piping and suffer no leak or condensation losses. As an auxiliary, the gas plant has no superior, for large quantities of gas can be stored in holders and be ready for service with the fires dead — the standby losses are less than for the steam plant and the smoke nuisance is eliminated; no small factor when one considers the pall which now hangs over most of our cities.

The waste heat from the gas engine exhaust can be utilized for heating purposes and from 2 to 3 lbs. of steam can be generated with any desired pressure up to 50 lbs. per each b.h.p.-hr.

The disadvantages of the gas plant are its high cost of installation and the fact that the engines must be operated at practically their "nominal capacity" with a "rated," or overload, capacity about 10% in excess of the "nominal." Reliability of service was at one time a formidable stumbling block which checked the progress of gas power plants, but this obstacle has now become a myth that need not be seriously regarded.

The producer gas plant should appeal particularly to all Maine power users, for many sections of the state are provided with an abundant supply of peat in accessible bogs, and this low grade fuel can be utilized most efficiently in a properly designed producer.

For a treatise on this subject see Bulletin 376, U. S. Geological Survey, Peat Deposits of Maine, by E. S. Bastin & C. A. Davis.

The word "peat" undoubtedly has a discordant sound to some owing to the many fake schemes which have been exploited having the ostensible purpose of drying, preparing and distributing peat for commercial uses. But this impression we trust will be dispelled by stating that instead of transporting the peat the gas plant should be located at the bog or mine, and the power generated should be transmitted electrically to its destination, following the same principle applied when a water power station is constructed on a river at some favorable site.

The peat for a producer requires no artificial preparation or manipulation other than that necessary to excavate, air dry and deliver to the furnace, because it can be fired when containing from 30 to 50% of moisture, a feat now being successfully accomplished in Europe on a commercial scale.

The cost for mining peat should not exceed $1 per ton, including delivering to the plant, and this cost can be entirely obliterated by the return from the by-products which can be derived if the installation is of sufficient size to warrant the cost of constructing a recovery plant for extracting the procurable sulphate of ammonia.

There is from 2 to 3% of nitrogen in American peats; as sulphate of ammonia, this material has a market price of 3 cts. per lb., costing about 1 ct. per lb. for reclamation. In each short ton of peat there are from 180 to 280 lbs. of sulphate of ammonia, and not less than 90 lbs. per ton can be produced commercially, having a value of $2.70 and costing about $0.90, showing a gross profit of $1.80 per ton of peat used as fuel. It is safe to state that the cost for

fuel in a peat gas plant would be nothing if it has 4,000 h.p. or more capacity, which is an amount sufficient to insure the economical production of ammonium sulphate.

The ordinary grades of bituminous coals contain about 80 lbs. of available sulphate of ammonia per short ton, and its recovery shows a corresponding return.

The writer feels certain that gas engine, peat or coal fired, auxiliary power plants will be extensively utilized locally in connection with hydro-electric installations at no remote future date.

OIL ENGINES

From a theoretical standpoint there is no fuel power so attractive as that afforded by the oil engine, and the ideal is now partially realized in actual practice, although the application of the oil engine has been much restricted on account of the exorbitant costs which have been maintained by the manufacturers holding the patent rights on the most successful types of oil engine equipment. Following the policy usually applied for determining the value of power, the cost of steam generated power has been taken as the base from which the sale price of oil engines was determined, establishing the cost for the oil apparatus at a figure just low enough to show a small margin of saving by its adoption, but in reality absurdly high when compared with the true cost of the equipment required. Such a procedure is shortsighted in the writer's opinion and this conclusion is apparently sustained by the purchasing public if we take the slow growth of the oil engine field in this country as a criterion upon which to base our decision.

The oil engine plant is very simple, comprising the engine proper, an air compressor and a fuel storage tank. It is ready for instant service without standby losses; there is no smoke nuisance; there is no dirt or dust such as accompanies the generating equipment of the steam and gas plants with their incumbent coal storage, and a minimum amount of operating labor is required. As against these advantages there exists the high cost of installation, with correspondingly excessive cost for repairs, and large single units have not yet been perfected in America. In all probability these two considerations will not long continue to offer obstructions against the more general application of this excellent prime mover, for the expiration of the "Diesel" patents already has created an undercurrent of activity on the part of the heavy machinery and engine builders which bids fair to cause brisk competition in the manufacture and sale of oil engine equipment, a condition that will of necessity incite perfection in design and reduce the initial cost.

It has been claimed that the future of the oil engine was threatened by the uncertainty regarding the ultimate cost of its fuel, on the ground that its extensive introduction would so increase the demand for oil that the supply would prove inadequate. At this time no one can foretell how much oil is available, but it is certain that there exist vast oil beds still undiscovered and that with a perceptible increase in consumption there will be an incentive to locate "strikes" which will substantially augment the present

supply, and no reason can be seen for anticipating any material increase in the cost of fuel oil.

Cost of Installations. The average cost for complete electric power plants of known "rated" horsepower capacity are given on Fig. 44. To obtain the cost for a contemplated plant it is necessary to determine the "load factor" which will establish the "nominal" and the "rated," or full, capacity required.

To secure a uniformity of comparison in illustrating the application of the diagrams which follow, 3 hypothetical operating conditions will be assumed for a proposed installation having a "rated capacity" of 4,000 e.h.p. and a "load factor" of 80%, making the "nominal" or "working capacity" 3,200 e.h.p. In the first case,

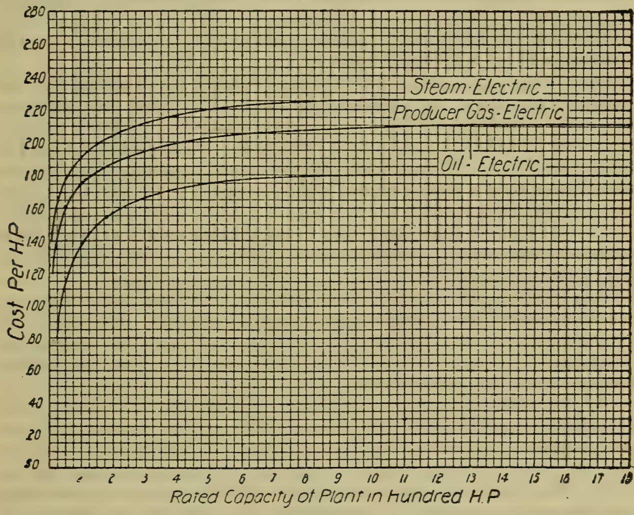


Fig. 44. Cost of complete electric power plants.

the plant operates for 300 days of 10 hrs. per day, or for a total of 3,000 hrs., and produces $3{,}200 \times 3{,}000 = 9{,}600{,}000$ h.p.-hrs. per yr. The total full capacity of the plant is $4{,}000 \times 8{,}760 = 35{,}040{,}000$ h.p.-hrs. per yr.; hence the "capacity factor" is $(9{,}600{,}000 \div 35{,}040{,}000) \times 100 = 27.4\%$. In the second case the plant operates for 365 days of 18 hrs., or for a total of 6,570 hrs., producing $6{,}570 \times 3{,}200 = 21{,}024{,}000$ h.p.-hrs. per annum, making the "capacity factor" 60%. In the third case the plant operates at its full "nominal capacity for 365 days of 24 hrs., producing 28,032,000 h.p.-hrs. per annum and having a "capacity factor" of practically 80%; all of the foregoing powers being measured at the station switchboard. The "capacity factor" can never be maintained continuously at

100% in any installation, because it would be impossible to design a plant which could be practically operated at its full "rated" capacity.

To obtain the costs of installation from Fig. 44, select the rated h.p. capacity of the plant as designed on the right-hand vertical margin and trace the horizontal line opposite the desired capacity to the intersection of the curves, then follow down the vertical line at these intersections to the cost per h.p., which is given on the lower margin. For example: The 1,500 h.p. horizontal intersects the "steam electric" curve at $56, the "producer gas" at $70 and the "oil electric" at $100, while for a 500 h.p. plant the intersections are at $63, $80 and $108, respectively. It will be noted that for "rated" capacities in excess of 1,500 h.p., the cost is practically constant, and, therefore, the cost for the 4,000 h.p. plant will be 4,000 × $56 = $224,000 for steam; 4,000 × $70 = $280,000 for gas, and 4,000 × $100 = $400,000 for oil.

Fuels. Fuel has a most important influence in affecting the cost of power and every effort should be made to reduce its consumption to the minimum amount consistent with the practical economical operation of the given system; but the necessity of utilizing fuel with a maximum economy has often been advocated when the expense of so doing would increase the cost per h.p. hr. for the power, owing to the refined apparatus required, with the greater interest and repair charges thus incurred, in addition to an increased labor cost due to the skillful mechanics required to properly operate the more complicated equipment.

It is lamentable to observe the painstaking efforts made by coal users to reduce the inroads into the coal pile by improving the mechanical conditions at their power stations, at the same time permitting the most slipshod methods to prevail when purchasing the commodity they so cherish. To purchase coal, or any form of fuel, by securing bids from reputable dealers for a certain trade grade shows an ignorance not encountered in the valuation of any other material. No buyer would pay for an ore except on the showing of its assay, which would be determined and certified by an expert. The merchant selects and pays for his cotton on the basis of its staple, not because it was grown in Alabama or Mississippi, but the manufacturer ordinarily makes his coal selection on name and price only, utterly disregarding the fact that he should endeavor to obtain a heat value return for his expenditure, and that no specific name, such as "New River, West Virginia, coal," or a dealer's business integrity will be a guarantee that he is getting his money's worth.

The measure of any fuel depends entirely on the number of available heat units which it contains, and it should be paid for on this basis. A unit of heat value is the British thermal unit (notation B.t.u.) and it is an inexpensive process to determine the quality of a fuel by making a "proximate analysis" that will show its B.t.u. content.

Consumers receiving their coal in consignments of 300 tons or over should always purchase under contract specifications that state

the price to be paid for the B.t.u. content of the coal; the actual price paid ter ton for the coal supplied to be established pro rata by test. It might be assumed that a single careful test of the coal for a given mine would be sufficient to insure a uniform quality, if it could be definitely proved that each shipment was made from the same mine; but this is not true, because the method of handling coal at the mines, in addition to the variation of the physical and chemical properties of the coal strata from the same mine, will occasion variation in quality which can only be determined by independent tests. The quality of the marketed coal depends in a large measure on the care taken in the preparation at the mines. Carelessness in picking slate or other impurities, or in jigging, or washing will produce a coal of inferior quality when compared with that secured from the same mine but carefully prepared; also bituminous coal, exposed to the atmosphere gradually depreciates in value and its moisture content has important bearing upon its available B.t.u. content. Buying coal by the ton in the ordinary manner often necessitates the purchasing of a large percentage of water and other impurities which are paid for and transported as coal, but which in reality have no fuel value.

The accompanying Table XXXVIII gives the average composition and heat value of several general classifications of fuels, also the producer gas that can be obtained from certain fuels on which reliable tests have been made.

The cost of coal has been constantly on the increase and it is most important that we consider its probable future cost by making a brief study of past conditions, for such study may occasion the selection of a power plant equipment that would otherwise be disregarded, if the present conditions alone are used in deducting the probable investment efficiency.

From 1870 to 1910 the population of this country increased from 38,000,000 to 92,000,000, or more than 142%, and the coal consumption increased per capita from 0.85 tons to 5.5 tons, or almost 550%; hence, in 40 years the coal consumption has increased about 4 times as fast as the population. During this interval the average value of coal property has increased from $100 to $2,000 per acre, or 1,900%, which is nearly 4 times the rate of consumption increase. When it is remembered that this phenomenal change in volume and value has been accompanied by a corresponding wage increase and more difficult engineering work in connection with the greater depth of the mines, it is a tribute to our application of scientific management in both mine working and transportation that we are not paying several hundred per cent. more for coal at this date than we are; but "coming events cast their shadows before" and the abnormal rise in mine values, together with the continual labor agitation, makes it almost certain that within a short period the cost of coal at the mines will be increased from 25 to 50% and that a greater proportionate increment of cost will be added as the coal passes the several go-betweens in its transition from the mine to the ultimate consumer.

Bituminous coal containing about 14,400 B.t.u. per lb. of fuel can

TABLE XXXVIII. AVERAGE PROXIMATE ANALYSIS OF FUELS

Class of fuel	Volatile — %	Fixed carbon — %	Moisture — %	Ash — %	Sulphur — %	Combustible — %	Fixed carbon in combustible — %	B.t.u. per lb. of combustible	B.t.u. per lb. of fuel as fired	Cu. ft. of gas per lb. fuel as fired	B.t.u. per cu. ft. of gas.	Specific gravity.	B.t.u. per gal.
Coal Anthracite, Pa.	3.81	83.80	3.61	8.42	.59	86.20	95.00	15,060	13,300	....	138	....	......
Semi-Anthracite, Pa.	6.74	85.08	1.41	6.28	.77	92.59	92.00	15,308	14,200	81	138	....	......
Semi-Bituminous, Pa., (Md., Va.)	18.62	72.40	.99	7.11	1.03	92.05	78.70	15,770	14,510	....	....	....	......
Semi-Bituminous (New River, W. Va.)	22.82	73.59	1.13	2.27	.41	96.82	76.00	15,731	15,230	92	153	....	......
Bituminous, Eastern	33.51	57.30	2.34	6.23	1.31	92.12	62.20	14,970	13,800	74	150	....	......
Bituminous, Western	36.10	45.50	7.95	10.48	1.79	83.39	54.60	13,460	11,230	52	147	....	......
Lignite, Texas	45.28	16.30	33.98	8.93	.89	62.47	26.10	13,250	8,280	32	162	....	......
Lignite, Wyoming	42.12	45.60	5.75	6.16	.64	88.72	51.50	13,767	12,200	....	....	....	......
Lignite, Colorado	35.00	49.30	11.99	3.76	.61	84.91	58.10	11,311	9,600	42	140	....	......
Lignite, Washington	35.73	53.60	2.52	8.14	.73	90.06	59.50	14,561	13,100	....	....	....	......
Peat	51.72	22.11	21.00	5.17	.45	74.28	29.80	10,900	8,127	30.30	175.2	....	......
Petroleum, Heavy, W. Va.	....	83.50	....	....	...	....	....	.....	18,324	....	....	0.873	133,300
Light, W. Va.	....	84.3	....	....	...	....	....	.....	18,400	....	....	0.8412	129,000
Heavy, Pa.	....	84.9	....	....	...	....	....	.....	19,210	....	....	.886	141,900
Light, Pa.	....	82.0	....	....	...	....	....	.....	17,930	....	....	.816	122,000
Heavy, Ohio	....	84.2	....	....	...	....	....	.....	18,718	....	....	.887	138,600
Lima, Ohio	....	80.2	....	....	...	....	....	.....	21,600	....	....	.79	......
Shoshone, Wyo.	....	....	....	....	...	....	....	.....	19,590	....	....	....	......
Oil Creek, Pa.	....	82.0	....	....	...	....	....	.....	20,890	....	....	0.73	127,200
California	....	....	....	....	...	....	....	.....	18,000	....	....	.95	142,700
Texas, Beaumont	....	81.6	....	....	...	....	....	.....	19,060	....	....	.92	146,000
Natural gas	....	....	....	....	...	....	....	.....	.....	....	1,000	....	......

Note.— One (1) barrel of oil contains 42 gallons.

now be purchased at the Maine coast for \$3 per long ton and it can be delivered to the station bunkers in most of our inland cities for a total of about \$4.60 per long ton. If this fuel is used under boilers of 78% efficiency, the lbs. of water evaporated, or the lbs. of steam generated, can be determined from the "boiler efficiency chart," Fig. 45, as follows: Locate on the lower margin of the diagram the vertical over the 14,400 B.t.u. and follow up on this

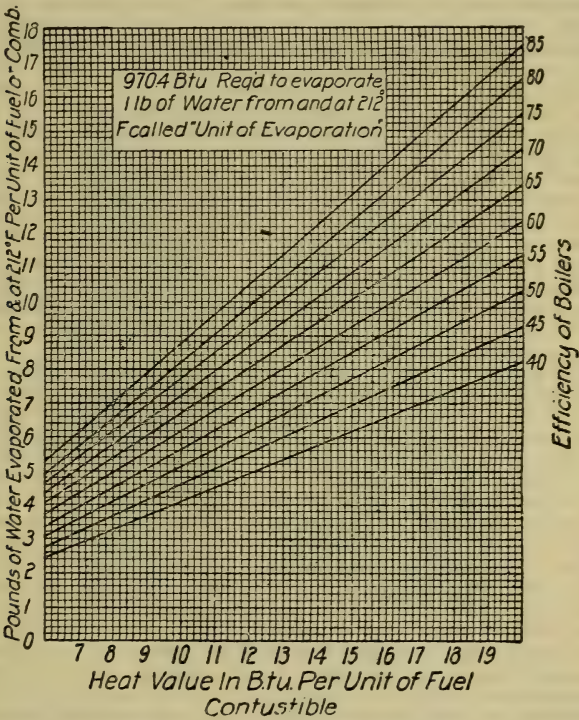


Fig. 45. Boiler efficiency chart.

line to the intersection of the diagonal line representing 78% boiler efficiency and read on the left margin the water evaporated, which is in this instance 11.5 lbs.

Any reputable boiler manufacturer can guarantee the efficiency of a boiler if he knows the quality of coal that will be used for with this information the proper ratio of grate and heating surface area can be provided.

The selection of a boiler, including its setting, must be made

with the same care and application of the specialist's knowledge as is devoted to any other accessory in a power plant. In many instances it can be shown, upon making a careful study of a problem, that a cheap grade of fuel with a low boiler efficiency is more economical than an expensive fuel yielding a high boiler efficiency. To prove this we will take a semi-bituminous fuel containing 14,400 B.t.u. per lb., costing \$4.60 per ton at the bunkers, and a low grade bituminous, such as Western, containing 11,230 B.t.u. per lb. and costing \$2.50 per ton delivered, using both in the same boiler furnace. The higher grade of coal will permit the practical operation of the boilers at an efficiency of 75% and the cheap grade with an efficiency of 60%. Referring to the diagram Fig. 45, it will be found that 11.2 lbs. of water can be evaporated with the good coal and 6.9 lbs. with the poor. This shows that the relative fuel value is as $6.9 \div 11.2 = 0.616$, and it will be necessary to use $1.00 \div 0.616 = 1.623$ tons of the cheap fuel to generate the steam that can be produced with 1 ton of the higher grade; therefore, $1.623 \times \$2.50 = \$4.06$ will be the cost of an equivalent amount of the lower grade coal. This shows that the supposedly poor fuel will yield $[(\$4.60 - \$4.06) \div \$4.06] \times 100 = 13.3\%$ better return for the same expenditure than the good. With the cheaper fuel more coal and ashes must be handled, increasing the labor expense proportionately, but this will not ordinarily be a sufficient amount to off-set a saving so great as that indicated above.

Holding to the example cited under "Cost of Installations," and the efficiencies given on the "Power Efficiency Diagram, Fig. 38," the cost for fuel can be derived from the diagram Fig. 46 as follows: One B.t.u. is equivalent to 778 foot pounds of energy, and one theoretical h.p. requires 33,000 foot pounds of energy per minute, and $33,000 \div 778 = 42.416 \times$ B.t.u., or 2,545 B.t.u. per hour. From Fig. 38 the total efficiency at the generator terminals, which will be practically the same as that at the switchboard, is shown on the fourth reading from the bottom to be 10.4%; hence the heat required to generate one e.h.p. at the switchboard will be $(2,545 \div 10.4) \times 100 = 24,471$ B.t.u., which will necessitate the consumption of $24,471 \div 14,400 = 1.7$ lbs. of coal per e.h.p.-hr. It has already been found from Fig. 45 that 11.5 lbs. of steam can be derived from 1 lb. of the above coal, and with this data from Fig. 46 can be determined the cost for fuel per e.h.p.-hr. and the pounds of steam generated per e.h.p.-hr. Locating on the lower margin the 1.7 lbs. of fuel per h.p.-hr. and following up this line until it meets the diagonal or the interpolated diagonal representing 11.5 lbs. evaporation, the steam consumption is found by following the horizontal lines to the left margin, reading in this instance 19.5 lbs. of steam per e.h.p. To obtain the cost of fuel per h.p.-hr., follow up the vertical corresponding to the required coal consumption until it meets the horizontal line corresponding to the cost per long ton of coal as given on the right-hand margin, reading on the curved lines, or interpolating between them if necessary, the cost per h.p.-hr. in cents and mills. With coal at \$4.60 per ton the cost will be \$0.0035 per e.h.p.-hr.

If the manufacturers of the boilers and engines state definite guarantee in specifications covering the operating conditions for their equipment, then Fig. 46 can be used directly for determining the cost of fuel. For example: The boilers are guaranteed to evaporate, with a given coal containing 14,400 B.t.u. and costing \$4.60 per ton, 10 lbs. of water per lb. of fuel. The boiler efficiency can be obtained from Fig. 45 by reading the nearest diagonal to the intersection of the vertical line corresponding to the 14,400 B.t.u. and the horizontal line reading 10 lbs. on the left margin, which will be 67.5%. The engine manufacturer guarantees that the engine

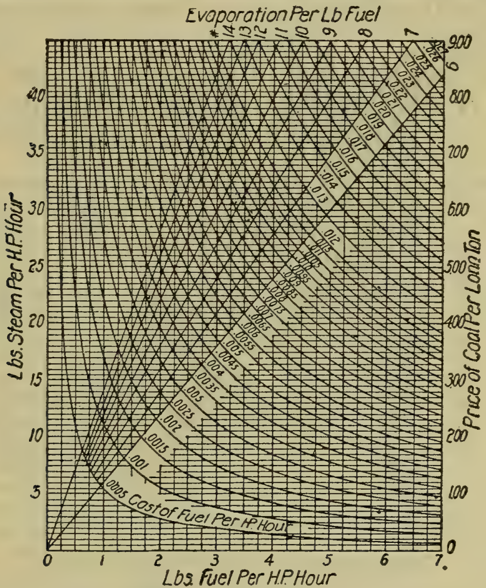


Fig. 46. Steam power — cost of fuel per horsepower hour.

alone will require 16 lbs. of steam per i.h.p.-hr., that the engine will have a mechanical efficiency of 95%, or that the steam per b.h.p.-hr. will be 16.84 lbs., and with a generator of 95% efficiency the steam consumption per e.h.p.-hr. will be $16.84 \div 0.95 = 17.73$ lbs. To this steam must be added the amount lost in radiation, pipe friction and auxiliaries, including the condenser, exciter, feed-water pumps, etc.; an amount varying from 5 to 15% of the steam required for the engines, depending upon the size of plant and the character of the auxiliaries; a fair average figure being about 9%; hence the total steam consumption per e.h.p.-hr. will be $17.73 \times 1.09 = 19.33$ lbs. On Fig. 46, tracing horizontally from 19.33 lbs. reading on the

left margin to the intersection of the diagonal corresponding to 10 lbs. evaporation the coal consumption per e.h.p.-hr. is read from the lower margin and is 1.93 lbs. Following up vertically opposite the same point of intersection to the line corresponding to $4.60 on the right margin and reading the nearest curve cutting this last intersection, we find that the cost for fuel per e.h.p.-hr. will be $0.004.

It will be noted that in almost all cases it will be necessary to interpolate the readings between the verticals representing the pounds of fuel per h.p.-hr. which are sub-divided in divisions of 0.25 lbs. each; and also the curves giving the cost for fuel per

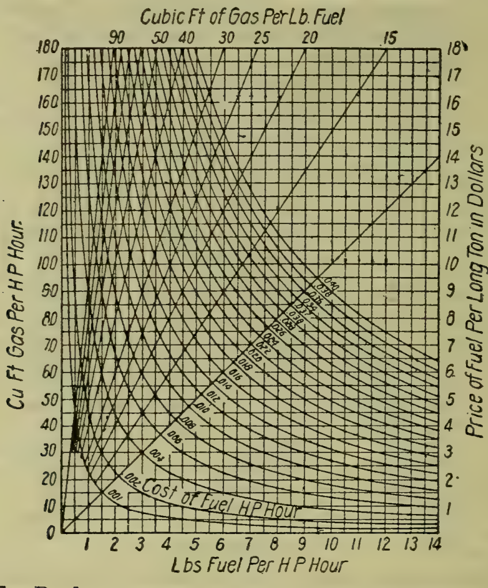


Fig. 47. Producer gas — cost of fuel per horsepower hour.

h.p.-hr. which are subdivided into one-half mill divisions, and this condition holds for all of the fuel Diagrams, Figs. 46, 47 and 48. With a little care in reading the results should be accurate within 0.5%.

The total annual cost for coal in the 3 hypothetical operating conditions for the 4,000 e.h.p. capacity steam plant previously described will be as follows: Case I — 9,600,000 e.h.p.-hrs × $0.0035 = $33,600; Case II — 21,024,000 e.h.p.-hrs. × $0.0035 = $73,584; and Case III — 28,032,000 e.h.p.-hrs. × $0.0035 = $98,112.

The fuel required in a gas plant of corresponding rated capacity

can be determined from Figs. 39 and 47. From Fig. 39 the net efficiency of the gas electric plant at the generator terminals, or the switchboards is 23.6%. Using the same grade of bituminous coal, as that employed in the steam plants, having 14,400 B.t.u. per lb. of fuel, the amount of coal required per e.h.p.-hr. will be $(2{,}545 \div 0.236) \div 14{,}400 = .75$ lbs. For one theoretical horse power requires 2,545 B.t.u. per hr., and with 23.6% efficiency, $2{,}545 \div 0.236 = 10{,}783$ B.t.u. will be required per e.h.p.-hr., or $10{,}783 \div 14{,}400 = 0.75$ lbs. of coal per e.h.p. With coal costing $4.60 per ton, the cost per e.h.p.-hr. from Fig. 47 can be obtained as follows: Locate on the lower margin the pounds of fuel per h.p.-hr. and trace vertically to the intersection of the horizontal line corresponding to the price of $4.60 on the right margin. The point of intersection in this instance falls about midway between the curves $0.001 and $0.002, hence the cost for fuel per e.h.p.-hr. is $0.0015, or per year for Case I — 9,600,000 e.h.p.-hrs. × $0.0015 = $14,400; for Case II — 21,024,000 × $0.0015 = $31,536, and for Case III — 28,032,000 × $0.0015 = $42,048.

The producer manufacturer can give definite guarantees for the efficiency of his equipment with a stipulated quantity of fuel. This efficiency will range from 60 to 80% depending upon the grade of fuel. From coal containing 14,400 B.t.u. with a producer efficiency of 80% — 11,520 B.t.u. will be delivered in the gas. The volumetric quality of the gas must be determined by test, and with the high grade fuel under consideration, approximately 80 cu. ft. of gas can be generated from one lb. of coal and one cu. ft. of gas will contain $11{,}520 \div 80 = 144$ B.t.u.

It is customary to guarantee gas engines on the basis of the gas consumption per b.h.p.-hr. On Fig. 39 the efficiency at the engine shaft is given as 24.8%, hence the efficiency of the engine is $(24.8 \div 80) \times 100 = 31\%$ and $2{,}545 \div 0.31$ B.t.u. will be required per b.h.p.-hr., or $8{,}210 \div 144 = 57 +$ cu. ft. of gas containing 144 B.t.u. per lb. With electric generators of 95% efficiency the cu. ft. of gas per e.h.p. hour will be $57 \div 0.95 = 60$. This figure can be checked from Fig. 39 as follows: $23.6 \div 0.80 = 29.5$ and $2545 \div 29.5 = 8627$ B.t.u. required per e.h.p.-hr., or $8627 \div 144 = 59.91$ cu. ft. of gas which is practically 60 cu. ft. as previously determined.

It must be remembered that the efficiencies given on Fig. 39 are for a gas electric power plant in perfect physical condition and skilfully operated. In ordinary practice it is to be expected that the figures would not obtain, particularly the engine efficiencies, as the manufacturers would be inclined to offer as a maximum guarantee the equivalent of 10 cu. ft. of gas containing 1000 B.t.u. which is equivalent to an efficiency of $2545 \div (10 \times 1000) \times 100 = 25.45\%$, making the total efficiency to the switchboard $25.45 \times .8$ (the producer efficiency) $\times .95$ (the gen. efficiency) $= 19.25\%$ instead of 23.6% as given on Fig. 39 and the coal consumption $(2545 \div 0.1925) \div 14{,}400 = 0.92$ lbs. per e.h.p.-hr. instead of the 0.75 lbs. previously given. To apply the diagram Fig. 47 with a known engine guarantee and quality of fuel the following example is cited: Given, a peat fuel from which 30.3 cu. ft. of gas containing 175.2 B.t.u. can

be generated per pound of fuel (see Table XL), costing $2 per long ton; an engine which is guaranteed to develop 1 b.h.p.-hr. with 12,264 B.t.u. or with 12,264 ÷ 175.2 = 70 cu ft. of gas and an electric generator efficiency of 91% making the cubic feet of gas per e.h.p.-hr. 70 ÷ 0.91 = 77. Locate on the left hand margin the 77 cu. ft. per h.p., follow horizontally to the right hand until the line intersects the diagonal representing 30.3 cu. ft. of gas per lb. of fuel, as noted at the top of the diagram; from this point of intersection drop vertically to the horizontal line corresponding to the price for

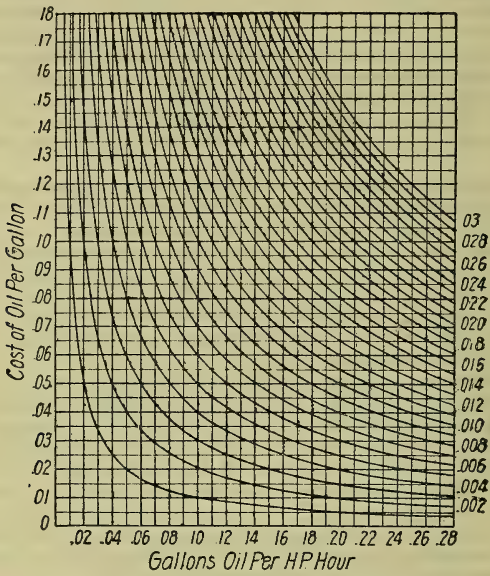


Fig. 48. Oil — cost of fuel per horsepower hour.

the fuel, as noted on the left margin, i.e. $2, and read from the curve the cost of fuel per h.p.-hr. which is in this case $0.002.

Fuel oil can be purchased locally for somewhat less than 3 cts. per gal. and the oil engine manufacturers will guarantee a consumption of 0.0755 gals. per e.h.p.-hr., including the auxiliaries, when the engine is direct connected to a generator of 95% efficiency. Knowing the cost of oil and the engine economy the cost per e.h.p.-hr. for fuel can be obtained from Fig. 48 as follows: Locate the gallons of fuel per h.p.-hr. on the bottom of the diagram and trace up vertically to the intersection of the horizontal corresponding to the price per gal. for oil as given on the left hand margin, reading the cost per h.p.-hr. from the curved line at the above intersection

which is with the foregoing conditions $0.0023. Then the fuel cost per year for a plant of 4,000 e.h.p. rated capacity will be: Case I — 9,600,000 × $0.0023 = $22,080; Case II — $48,355, and Case III — $64,474.

Labor. The operators, including all of the laborers employed in connection with the operation of a plant, exclusive of those engaged on its repairs, are the sole influence which can make it produce power with efficiency and economy. No matter how carefully the

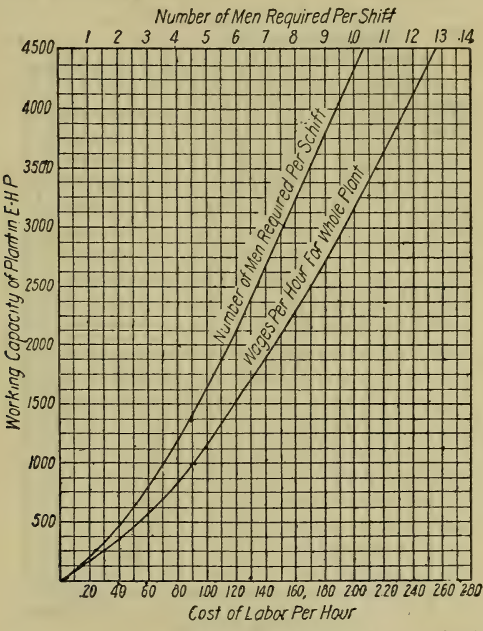


Fig. 49. Cost of labor; steam electric plants.

designing engineer selects the equipment and arranges the layout; no matter how finely balanced and adjustable the entire scheme may be, to meet the requirements of a particular service, unless the controlling labor organization is trained to realize to the best advantage all of the facilities afforded, no amount of perfected appliances can compensate for unskillful manipulation! This statement does not mean that a power station must be manned by a crew of skilled mechanics, or power experts, or that it must be operated by a set of theoretical rules, that would, undoubtedly, defeat the very purpose for which they were created; but it does mean that each department must be under the control of men who know what the

apparatus is supposed to accomplish and who are fully conversant with the various combinations and adjustments that will yield the desired result. It is not even necessary and often inadvisable for the attendants to know *why* certain conditions obtain with a given combination provided they are certain that they *do* accomplish certain results.

It is important that one man should be thoroughly familiar with each and every detail of a given plant, and that he have full charge

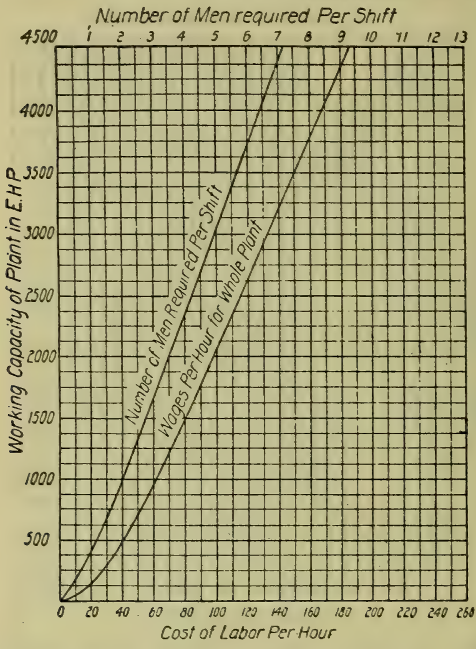


Fig. 50. Cost of labor; producer gas electric plants.

of its operation. Beyond this single competent operator, or supervisor, the assistants need not be specialists except as they become trained to deftly perform the certain specific duties placed upon them. The proverb that "a little learning is a dangerous thing" applies aptly to the station operator who has acquired a sufficient insight into the mechanics of his work to incite his constant tinkering with the equipment, making minor adjustments and changes here and there, until he inadvertently oversteps his knowledge and causes a mixup which damages or demolishes thousands of dollars' worth of machinery. A skillful commander, with a corps of well

trained privates, faithful in the performance of the duties consigned to them, forms a much more satisfactory and safe working crew for a power station than a contingent of petty officers each impressed with the importance of his position and ability.

The labor required for a given plant depends upon the "rated" working capacity and the hours of operation per year. The rated or normal capacity of the 4000-h.p. plant under consideration is 3,200 e.h.p. Figures 49, 50 and 51 show the number of men required per shift, and the average wages per shift per hour for steam, gas

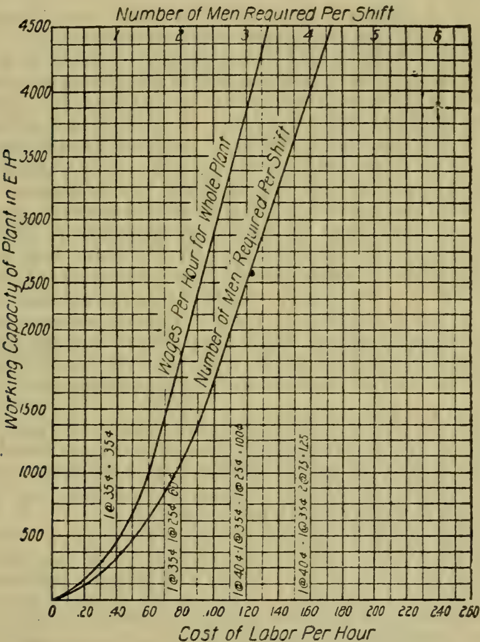


Fig. 51. Cost of labor; oil electric plants.

and oil electric power plants. These diagrams do not include the repair crew, which may or may not comprise part of the station organization depending on whether or not the plant is co-related to some industry, or is an isolated proposition. From Fig. 49 the cost for labor per e.h.p.-hr. in a steam electric plant of 3,200-h.p working capacity is found by locating on the left margin 3,200 h.p., and following this line horizontally to the right to the intersection of the curve marked "Wages per hour for whole plant" and reading from the vertical at this intersection, on the lower

margin the amount, which is \$2.02. Then the cost per year for labor will be in Case I — 3,000 hrs. × \$2.02 = \$6,060; Case II — 6,570 hrs. × \$2.02 = \$13,271, and Case III — 8,760 hrs. × \$2.02 = \$17,695.

The wages for gas and oil plant operation are similarly determined from Figs. 50 and 51, and are as follows: For gas, Case I — 3,000 × \$1.41 = \$4,230; Case II — 6,420 × \$1.41 = \$9,264, and Case III — 8,760 × \$1.41 = \$12,352, and for oil, Case I — 3,000 × \$1.12 = \$3,360; Case II — 6,570 × \$1.12 = \$7,358, and Case III — 8,760 × \$1.12 = \$9,811.

When the oil engine is constructed in larger units than the present standard, the operating labor cost will be reduced.

Depreciation, Repairs and Improvements. There is a wide divergence of opinion as to the method of computing or allowing for depreciation in connection with power plants, and, in fact, as to the true meaning of the term "depreciation." Its literal definition is "the act of lessening the worth of"; hence all factors which lessen the value of a plant must be taken into consideration, including wear, inadequacy, age and obsolescence. It is claimed by many managers that the repairs and improvements made in the ordinary course of operation cover all that it is necessary to allow for depreciation, reasoning on the theory that if a plant is kept in prime physical condition it appreciates. This logic may at first sound reasonable and it is practically true so far as the immediate physical condition is concerned, but in time if this policy was pursued to its ultimate limit, it will be found that repairs will not longer keep the equipment in working order and renewals become imperative, hence age occasions an expenditure which is chargeable to the *past* operation.

Should the growth of a power service be rapid, the demands upon the equipment and buildings may soon exceed their capacity, then the value of a plant in perfect condition may be suddenly reduced, due to its inadequacy, and its compulsory abandonment incurs an expense which is chargeable to *past* operation.

If improvements in apparatus are devised which make the equipment of a plant inefficient when compared with the more recent developments, economy demands that the inferior outfit should be supplanted, and the discarding of apparatus mechanically in excellent preservation, occasions a depreciation in its value, due to obsolescence which is chargeable only to *past* operation.

A depreciation allowance does not mean expenditure, but the setting aside of certain sums in anticipation of future losses from any or all of the above causes, thus making the project self-sustaining from its inception.

There is no definite basis or established standard for determining the amount of depreciation to be allowed per annum for the several component parts of a power plant, this condition is largely due to the contradictory decisions that have been rendered by the courts in relation to this subject, combined with the entirely different view-points which must be assumed when placing the depreciation

on a projected plant on a "going" proposition. In the first instance it becomes necessary to assume a reasonable period of normal life, and to distribute the depreciation reservations in some equitable manner over this period, so that at the end of the predetermined time there will be available a sum sufficient to replace the property. In the case of a "going" proposition the theoretical depreciation as previously outlined cannot be justly applied, for a plant may have nearly reached its theoretical limit of life yet still be in such excellent physical condition that it fully meets the requirements of the imposed service, and to deduct from its cost the theoretical depreciation would make its present worth only the scrap value of the equipment, an appraisal which the actual conditions controverts.

For buildings of a permanent character from 1 to 1.5% of the cost per annum has been found to be a sufficient allowance for depreciation; for steam engines and turbines from 3 to 6%; for electric generators, from 3 to 7%; for boilers, from 5 to 10%; for steam pumps, from 5 to 7%; for switchboards, from 3 to 5%; for condensers, from 4 to 10%; for gas producers, from 3 to 8%; for gas and oil engines, from 4 to 7%, and for machinery foundations, the same as that allowed for the apparatus which they support.

The average depreciation per annum for a complete steam electric power plant will be about 4% of its total cost for a gas electric plant, 5%, and for an oil electric plant 5.5%; provided the property is kept in good physical condition by proper maintenance and repairs.

On the basis of the above percentages, the annual depreciation for the hypothetical plants cited, will be as follows: for steam, $224,000 × 0.04 = $8,960; for gas, $280,000 × 0.05 = $14,000, and for oil, $400,000 × 0.055 = $22,000.

The hours of operation have but slight bearing on the depreciation of equipment, for if kept in proper repair, continuous operation does not cause much greater depreciation than that occasioned by intermittent service, in fact, power equipment operating for only a portion of the time is subjected to temperature strains that are more conducive to its destruction than the mechanical wear that is imposed upon it by continuous operation; but the cost of maintenance, repairs and supplies varies proportionally with the "capacity" factor.

The repairs and supplies, including labor and materials, for steam plants having from 80 to 100% "capacity" factor, will be about 2% of the first cost; for from 50 to 80% cap. factor, 1.75% of cost, and for from 20 to 50% cap. factor, 1.5% of cost; and for oil and gas plants, with 80 to 100% cap. factor, 2 5%, from 50 to 80% cap. factor, 2%, and from 20 to 50% cap. factor, 1.75%.

Then for the hypothetical plants, the annual repairs and supply cost will be:

Case I—

Steam	$224,000 × 0.015 =	$3,360
Gas	280,000 × 0.0175 =	4,900
Oil	400,000 × 0.0175 =	7,000

Case II —

Steam	$224,000 × 0.0175 = $3,920
Gas	280,000 × 0.02 = 5,600
Oil	400,000 × 0.02 = 8,000

Case III —

Steam	$224,000 × 0.02 = $4,480
Gas	280,000 × 0.025 = 7,000
Oil	400,000 × 0.025 = 10,000

Taxes, Insurance and Interest. The taxation charges depend entirely upon local conditions, but it is safe to assume that the valuation placed upon power plant property will not exceed 60% of its first cost, or the replacement cost, and that a fair average rate of taxation in Maine will be 2%. Insurance rates also depend upon local conditions, but 0.5% on 60% of the property cost is about a fair average allowance. Estimating on 2.5% of 60% of the cost for the plants under discussion, the annual charges for taxes and insurance will be as follows:

Steam	0.60 × $224,000 × 0.025 = $3,360
Gas	0.60 × 280,000 × 0.025 = 4,200
Oil	0.60 × 400,000 × 0.025 = 6,000

The interest charges are readily obtained for an independent power plant depending for its solvency on an income from the sale of power, as the capitalization and the accounting are not involved with other branches of industry; but a power plant built and operated in conjunction with a mill offers a more difficult problem, as the separation of accounts will usually demand some abstruse disbursements of costs which may either favor or handicap its showing. The thoughtful business man will concede that the power plant should pay for itself, and that the power to adopt will be that which yields a maximum return on the *total investment* for the entire mill property.

A shoe manufacturer would not entertain a proposition for the preparation of his own leather if by so doing he reduced the net per cent. of profit on the whole plant investment, even though the annual expenditure for leather was materially reduced, and the same process of reasoning should be applied to the generation of power. To illustrate this point more clearly; we will take the specific case of an industry which has a total capitalization of $500,000 and yields a net profit of 15% on the investment, when run with purchased power. By making an additional investment of $100,000 the power can be produced on the mill premises for a cost sufficiently less than that paid for the purchased power to yield a return of 6% on the power plant investment. The total capitalization for the industry now becomes $600,000 and the net profit ($500,000 × 0.15) + ($100,000 × 0.06) = $81,000, or a return on the total investment of 13.5 per cent., and the relative earning power of the property has been reduced (15 — 13.5 ÷ 15) × 100 = 10%.

It follows that while it is justifiable to use a uniform rate of

interest when comparing the cost for several different classes of power, in adopting a power to be used in connection with any industry, it is important that it be selected on the basis of its intrinsic value to the entire project, and not on its relative power value.

For the purposes of comparison, we have assumed an interest of 5% on the cost of the projects, as follows:

Steam	$224,000.00 × 0.05 =	$11,200.00
Gas	280,000.00 × 0.05 =	14,000.00
Oil	400,000.00 × 0.05 =	20,000.00

Water, Land Rental and General Expenses. In the estimates for cost, no allowance has been made for water charges, land rental or general expense. These items will vary for each locality and are readily ascertained, with the exception of general expenses which will be regulated by the policy of the managers. If large quantities of fuel and supplies are constantly maintained, the interest on the money thus invested should be charged to the plant operation; and if a large volume of coal is stored for a considerable period, a deterioration of about 5% for each 6 months in storage should be added to the power cost; as should also be the costs for clerical work devoted to the ordering and disbursing of supplies and materials, and employed in compiling the records of the plant operation.

In most sections of Maine, water for boiler feed, condensing and cooling purposes can be secured without other cost than that required to provide proper facilities for delivering it to the desired point of use. If the water must be purchased, or if it becomes an item of considerable expense, provision should be made for its economical utilization, and cooling towers, or pools, should be installed to conserve the condensing water for steam plants and the cooling water for gas plants. The use of surface condensers will permit the return of all the condensed steam to the boiler with the exception of about 5% which will be lost mechanically while passing through the system. Provision should be made for supplying the condensers with about 50 times the amount of water required for steam, and for supplying gas plants about 200 lbs. of water per e.h.p.-hr.

The land rental is not ordinarily an important factor in local power costs except in congested cities where real estate is high; and the proper amount to be added for this item is readily obtained for any specific case.

Conclusions. Table XLI gives a résumé and summation of the figures relating to the hypothetical plants, which are distributed through the preceding text, and it shows the *lowest* costs that can be realized when generating power in plants of the several types outlined, and operating under the most favorable conditions. The only items that can be reduced are the fuel charges. The writer wishes to place particular emphasis on the foregoing statement and to impress upon the readers' attention the fact that the final figures, under items Nos. 35 and 36, for the cost per h.p. and kw.-hr., are

TABLE XLI. COMPARISON OF HYPOTHETICAL PLANTS

Item	Case I			Case II			Case III		
	Steam	Gas	Oil	Steam	Gas	Oil	Steam	Gas	Oil
1. Rated e. h.p. capacity of plant	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
2. Normal e. h.p. capacity of plant	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200
3. Hours operation per year	3,000	3,000	3,000	6,570	6,570	6,570	8,760	8,760	8,760
4. Load factor, %	80	80	80	80	80	80	80	80	80
5. E. h.p.-hr. generated per year, thous.	9,600,	9,600,	9,600,	21,024.	21,024,	21,024,	28,032,	28,032,	28,032,
6. Capacity factor, %	27.4	27.4	27.4	60	60	60	80	80	80
7. Cost of plant per e. h.p. of rated capacity	$56.00	$70.00	$100.00	$56.00	$70.00	$100.00	$56.00	$70.00	$100.00
8. Cost of complete plant	$224,000	$280,000	$400,000	$224,000	$280,000	$400,000	$224,000	$280,000	$400,000
9. Price of fuel per long ton	$4.60	$4.60	$9.60	$4.60	$4.60	$9.60	$4.60	$4.60	$9.60
10. Price of oil per gal.	......	....	$0.03	......	......	$0.03	......	......	$0.03
11. Efficiency of boilers or gas producers, %	78	80	....	78	80	......	78	80	......
12. Efficiency of complete oil equipment, %	......	....	26.1	......	......	26.1	......	......	26.1
13. B.t.u. per lb. of fuel	14,400	14,400	18,400	14,400	14,400	18,400	14,400	14,400	18,400
14. Lb. of steam per lb. of coal	11.5	....	....	11.5	......	......	11.5	......	......
15. Lb. of fuel per e. h.p.-hr.	1.7	0.75	0.53	1.7	0.75	0.53	1.7	0.75	0.53
16. Lb. of steam per e. h.p.-hr.	19.5	....	....	19.5	......	......	19.5	......	......
17. Cu. ft. of gas per lb. of fuel	......	80	....	......	90	......	......	80	......
18. B.t.u. per cu. ft. of gas	......	144	....	......	144	......	......	144	......
19. Cu. ft. of gas per e. h.p.-hr.	......	60	....	......	80	......	......	60	......
20. B.t.u. per gal. of oil	......	....	129,000	......	......	129,000	......	......	129,000
21. Weight of one gal of oil, lb.	......	....	7.03	......	......	7.03	......	......	7.03
22. Gal. of oil per e. h.p.-hr.	......	....	$0.0755	......	......	0.0755	......	......	0.0755
23. Cost of fuel per e. h.p.-hr.	$0.0035	$0.0015*	$0.0023	$0.0035	$0.0015*	$0.0023	$0.0035	$0.0015*	$0.0023
24. Cost of fuel per yr., No. 5 × No. 23	$33,600	$14,400	$22,080	$73,584	$31,536	$48,355	$98,112	$42,048	$64,474

Item	Case I Steam	Case I Gas	Case I Oil	Case II Steam	Case II Gas	Case II Oil	Case III Steam	Case III Gas	Case III Oil
25. Cost of labor per hr....	$2.02	$1.41	$1.12	$2.02	$1.41	$1.12	$2.02	$1.41	$1.12
26. Cost of labor per yr., No. 3 × No. 25	$6,060	$4,230	$3,360	$13,271	$9,264	$7,358	$17,695	$12,352	$9,811
27. Percentage of first cost allowed for depreciation, %	4	5	5½	4	5	5½	4	5	5½
28. Annual depreciation....	$8,960	$14,000	$22,000	$8,960	$14,000	$22,000	$8,960	$14,000	$22,000
29. Percentage of first cost allowed for repairs and supplies	1.5	1.75	1.75	1.75	2	2	2	2.5	2.5
30. Annual repair and supply cost	$3,360	$4,900	$7,000	$3,920	$5,600	$8,000	$4,480	$7,000	$10,000
31. Taxes and insurance at 2½% of Item No. 8 × 0.6	$3,360	$4,200	$6,000	$3,360	$4,200	$6,000	$3,360	$4,200	$6,000
32. Interest on cost at 5%..	$11,200	$14,000	$20,000	$11,200	$14,000	$20,000	$11,200	$14,000	$20,000
33. Total annual expenditure items, Nos. 24 + 26 + 28 + 30 + 31 + 32 ...	$66,540	$55,730	$80,440	$114,295	$78,600	$111,713	$143,807	$93,600	$132,285
34. Cost per e. h.p.-hr., No. 33 ÷ No. 2..........	$20.79	$17.42	$25.14	$35.72	$24.57	$34.91	$44.94	$29.25	$41.34
35. Cost per e. h.p.-hr., No. 33 ÷ No. 5	$0.00693	$0.0058+	$0.00838	$0.00544	$0.00374	$0.00532	$0.00513	$0.00334	$0.00472
36. Cost per kw.-hr., item 35 × 1.25	$0.00866	$0.00725+	$0.01047+	$0.00680	$0.00467	$0.00665	$0.00641	$0.00417	$0.0059

Note.— *No allowance has been made for the return from reclaiming sulphate of ammonia.

minimum, and that the average cost for power as produced by plants running in connection with an industry will be about 20% higher than those recorded in the tabulation.

As intimated in the introductory remarks, this paper is prepared with the object in view of aiding in the education of the public in regard to the real value of Maine's water-powers, at the same time we hope its perusal will dispel any illusions that may exist as to the possibility of generating steam power in Maine for $15 or $16 per h.p.-yr. of 3,000 hrs., a falsity which we know has been occasionally credulously accepted; but such an accomplishment is impossible unless a portion of the power expenditure is eliminated by disbursing it with process accounts; a procedure justified only when steam is required for process, or heating purposes.

It is more than probable that the necessity of insuring continuous operation will compel the installation of reserve equipment in plants working under the conditions outlined for Cases II and III, although no allowance has been made for this contingency in the plants cited. The need for surplus apparatus is more urgent (becoming almost imperative if power interruptions are to be avoided) in gas and oil plants, on account of the small overload capacity of the engines; when compared with the steam engine or turbine that can carry as high as 50% overload in an emergency by sacrificing efficiency. To meet the requirements by installing surplus apparatus will add materially to the cost per h.p.-hr., as items Nos. 27 to 33 inclusive will be increased.

Fully appreciating all of the foregoing facts, the author deemed it advisable to adhere to the simple cases adopted rather than enter into the details of the more involved problem with the attendant discussion; because the examples given quite clearly illustrate the application of the diagrams, with less opportunity for confusion in demonstrating their use than would exist if the problems were more complex.

Obviously the data presented cannot be applied indiscriminately, for it is not to be expected that any stereotyped code of rules can be made which will eliminate the need of applying discerning judgment; or that the information given will obviate the necessity and advisability of obtaining the counsel of an expert when a proposition of importance is under consideration.

Comparative Cost of Power by an Oil Engine and a Steam Engine in Small Units. E. H. Lockwood and F. P. Pfleghar gave the following notes at the meeting of the A. S. M. E., November, 1912.

The steam engine was a 100-h.p. horizontal Putnam with a Fitzgibbons boiler of the same rated boiler h.p. The oil engine was a De La Vergne, horizontal, single-acting, center crank, 4-stroke cycle; jacket, water-cooled; fuel, petroleum fuel oil; ignition, hot chamber, on the Hornsby-Akroyd system; cylinder dimensions, diam. 27 ins., stroke 33 ins., rated h.p. 125, used to drive a direct-connected 220-volt generator, the current being used for light and power, and the average output being about 90 h.p. The engine was carefully tested for output and fuel consumption and found quite economical. The actual cost of operation of the oil engine follows:

Fuel oil, 14 gal. per day	$3.78
Labor, half-time of one man	1.50
Oil, waste, water, repairs, per day	1.00
Total cost per day	$6.28

On a basis of 300 days per year, the above amounts to $20.93 per h.p. per yr.

The fixed charges for this engine were as follows:

Cost of engine and generator, 10% of $6000	$600
Cost of heating boiler, 10% of $1000	100
Insurance, taxes, etc., per yr.	250
Fixed charges per yr. per h.p.	$10.55

Combining these two costs, the total cost per h.p. per yr., including operation and fixed charges, was $30.48.

Apparently the 10% given in the preceding table is intended to cover interest and depreciation, which is the same basis assumed for the steam engine.

In contrast with the preceding, the estimated cost of operating the steam engine was as follows:

Fuel per day, 2¼ tons	$ 8.21
Labor, time of one man	3.00
Oil, waste, etc., per day	0.50
Total per day	$11.71

On a basis of 300 days, and divided by 90 h.p., the above cost amounts to $39.04 per h.p. per yr.

The fixed charges for this engine were as follows:

Cost of steam engine and generator, 10%	$350
Cost of boiler, 10%	200
Repairs, insurance, and taxes	250
Total fixed charges per yr.	$800
Fixed charges per yr. per h.p.	$8.88

The two costs combined giving a total of $47.92 per h.p. per yr. for operation and fixed charges.

This showing is favorable to the oil engine, if no account is taken of the useful by-product of exhaust steam which was utilized for 7 months of the year when the factory was heated. The allowance that was made for this steam was arrived at by deducting the cost of coal required for heating, which was estimated as 1 ton per day for 7 months, or $766. With this correction the total cost of the steam engine was reduced to $39.38 per h.p. per yr. as compared to $30.48 for the oil engine, both of these being on the basis of 1 h.p. per day of 10 hrs., 300 days per yr.

In the discussion attention was called to the fact that the bad features of the oil engine are necessity for heating it for 20 minutes or so before it starts, the expense of frequent renewals of caps, irregular work of the generator when directly connected to the shafts and higher expenses for keeping up the engine than in the

case of the steam engine. The oil engine generally gives more trouble and is less economical in winter.

Cost of Power with Small Unit. Engineering and Contracting, April 3, 1912.

Cost at 45 h.p. Producer Plant. The plant is installed in a woodworking shop of the Lampsen Lumber Co., New Haven, Conn., and the records were presented by Albert W. Honywell, Jr. The engine is rated at 45 h.p. at 160 rev. per min. and is of the 4-cycle hit-and-miss type, with poppet valves and jump-spark ignition. The producer is of the ordinary suction type, with stationary grates, and the quantity of gas delivered to the engine is varied by a hand-adjusted throttle valve in the delivery pipe. The plant is in operation 9 hrs. a day, the engine kept running noon hour, and the load variable.

The average coal consumption is approximately 467 lbs. of pea anthracite per day, or 46.7 lbs. per hr. Assuming an average load factor for the shop of approximately 40%, this is equivalent to 2.5 lbs. of coal per h.p.-hr. The cost of coal delivered is $4.50 per ton, which would give an average cost per b.h.p. per hr. of 0.56 cts. No account is taken of the cost of water, as the only cost is that of pumping.

The first cost of the plant, including producer, engine, blower and motor to drive same, was, in round figures, $3,500. The operating expenses per day were found to be:

Coal, 467 lb at $4.50 per ton	$1.05
Labor	2.50
Repairs and depreciation	1.16
Interest and taxes	0.70
Oil and waste	0.14
Total	$5.55

The ashes from the producer were, however, screened, and coal secured in this manner may be estimated at $2 per ton, which reduces the real operating expenses to $5.08 per day.

Comparative Figures for 500 h.p. Oil Burning Steam Plant Converted to a Diesel Engine Drive. Electrical World, May 25, 1912. Table XLII gives the figures from the record of a month's operation in 1910 and one in 1911 of a plant in the Southwest. The first column is for all-steam operation, the second for all-Diesel operation.

TABLE XLII

	Steam	Diesel
Kw.-hr. produced	38,402	63,780
Kw.-hr. per lb. fuel oil	0.205	1.280
Kw.-hr. per gal. fuel	1.54	9.49
Total manufacturing cost	$884.86	$646.08
Operating cost	844.24	530.69
Maintenance cost	40.62	115.39
Power plant wages	210.00	251.70
Fuel for power	540.00	179.34
Water for power	65.00	32.50
Miscellaneous operating expense	16.95	25.12

Maintenance:

Boilers	$60.85	......
Engines	10.65	$95.67
Electric plant	8.85	10.97
Miscellaneous	12.75	8.75
Buildings	7.25	......

Comparative Cost of Electricity Generated by Gas and Steam Engines. Very interesting data comparing the cost of generating electricity at a small isolated plant near Boston are contained in the October, 1910, issue of The Isolated Plant, from which we have abstracted the following:

The generating equipment is run in conjunction with the steam heating plant in an establishment combining the features of a hotel and boarding house. Due to the necessity of enlarging the plant and replacing a worn-out unit and to the fact that the economy of gas engine generating sets had been presented in an extremely favorable manner, this type of equipment was installed.

The installation consisted of:

1 85-h.p. gas engine, 262 rev. per min. direct connected to 50-kw. generator.
1 40-h.p. gas engine, 300 rev. per min. direct connected to 25-kw. generator.
5 panel switchboard and wired with duplicate balancer sets for 125 volt lighting, and cost $8,100.

With gas at 60 cts. per thousand cu. ft., the cost of fuel for the gas engine sets amounted to about $350 per month, making the total cost for fuel of steam and electric plant about $175 a month more than for the years 1904, '05 and '06, when the entire plant had been operated with steam.

The boilers used were 2 125-h.p. horizontal tubular, which were retained from the first installation.

The fact that operating costs outside of fuel were also increased, making a total increase in cost of about $2,000 per yr., convinced the management that in this case, steam operation was decidedly more economical, and the following equipment was installed:

1 125-h.p. engine, 275 rev. per min. direct connected to 75-kw. generator.
1 40-h.p. engine, 300 rev. per min. direct connected to 25-kw. generator.
5-panel switchboard.
2 balancer sets.
2 watt hour meters, 300 and 200 amp.
All installed and wired complete for $5,100.

The exhaust steam from the engines is utilized in heating during the winter; in summer after passing through the feed water heater, it is exhausted directly to atmosphere.

Tables XLIII and XLIV show the comparative costs of operating the 2 systems:

Labor is made up of .5 the time of the chief engineer and full time for second and third assistant engineers.

TABLE XLIII. ANNUAL COSTS, GAS ENGINE PLANT

	Annual cost	%	Per kw.-hr. ct.
Labor	$2,230	30.10	1.344
Gas at 60 ct. per M.	3,379	45.61	2.037
Oil	255	3.44	0.154
Miscellaneous supplies	75	1.01	0.045
Electrodes	180	2.43	0.045
Repairs	200	2.70	0.120
Fixed charges (replacement, 5%, $405; interest, 5%, $405)	810	10.93	0.488
Insurance (liability)	30	0.40	0.018
Taxes	25	0.34	0.015
Overhead	225	3.04	0.136
Totals	$7,409	100.00	4.465

TABLE XLIV. ANNUAL COST STEAM ENGINE PLANT

	Annual cost	%	Per kw.-hr. ct.
Labor	$1,640	48.87	0.988
Coal	591	17.61	0.357
Water	120	3.58	0.072
Oil	75	2.23	0.045
Miscellaneous supplies	40	1.19	0.024
Repairs	125	3.72	0.075
Fixed charges (replacement, 5%, $255; interest, 5%, $255)	510	15.20	0.307
Insurance (liability)	30	0.89	0.018
Taxes	25	0.75	0.015
Overhead	200	5.96	0.121
Totals	$3,356	100.00	2.022

TABLE XLV. KW.-HR. COSTS

	Gas ct.	Steam ct.
Labor	1.344	0.988
Fuel	2.037	0.357
Incidentals	0.427	0.141
Charges, etc.	0.657	0.536
Total	4.465	2.022

Use of coal in each case may be shown as follows:

Actual coal used, January to June inclusive, 1909, when running with gas engines,	695 tons
Annual use, 695 ÷ .53, heating, etc.	1,311 tons
6 months' use of coal with steam engine in 1910	769 tons
Annual use, all purposes	1,451 tons
Deduct power use	140 tons
	1,311 tons

TABLE XLVI. TOTALS, HEATING AND POWER PLANT

Electric light and power, 165,923 kw.-hr.	$ 7,409	$3,356
Additional fuel, 1,311 tons at $4.25	5,572	5,572
Add gas fuel	.....	55
	$12,981	$8,983

Electrodes. The make and break method of sparking is used on the engines, and the electrodes proved rather an expensive item.

Overhead is a proportionate charge for management and office expense.

Labor is made up of ⅓ the time of the chief engineer, .5 the time of first assistant engineer and full time of the second assistant engineer; after stopping the gas engines the third assistant engineer was no longer needed.

Coal. The maximum quantity has been used, 140 tons at the prevailing price of $4.22. No reduction has been made for greater efficiency of operation with 2 engines, although all fixed charges have been based on the investment required for 2 engines.

Water. Full charge for the steam exhausted would be about $200, but as the exhaust is entirely used in winter for heating and is put through the feed water heater in the summer, this cost has been reduced 40%. Remarks under table on "charges" and "overhead" apply in this case also.

The kw.-hr. costs, grouped for comparison, are shown in Table XLV.

Costs of a Gas Engine and of a Combined Steam Plant. The following is abstracted from an article by T. M. Chance in the Engineering Record, Sept. 4, 1909. In the many excellent articles upon the relative financial economy of steam and gas-driven stations which have appeared in the technical press of the last few years the issues have been variously discussed and reliable data furnished from which somewhat definite conclusions may be drawn as to which of the two is preferable for any particular service. At or near full load the gas engine so far has shown a decided economic superiority and even in the lower ranges of load-factor is an important rival of the engine or turbine-driven steam plant; but the first cost of a gas engine, with its producer, scrubbers, and auxiliaries, is high, and where cheap anthracite or coke cannot be had, the operation of the producer on soft coal requires more intelligent attendance and skill than the steam boiler.

If a plant can be installed that will have the small first cost and low fixed charges of the steam plant and at the same time approach the gas engine in low operating costs, without, however, the necessity of a troublesome bituminous producer, it will go far toward a satisfactory solution of the power problem. In the past two years such a solution has been found in the adoption of the low-pressure turbine, utilizing the exhaust of high economy Corliss steam engines.

For the purpose of comparing the economy of this type of power plant with that of the gas engine, the total cost of operating and maintaining, under like conditions, a 1000-kw. plant of each type will be considered. It must be borne in mind, however, that the conclusions so reached apply with even greater force to larger sized stations, as the first cost per kw. of the combined steam plant decreases more rapidly as the power per unit increases than does that of the gas plant. We will assume the locality to be one in which good steam coal can be bought for $1 to $4 a ton, condensing

water to be plentiful and at a fair mean temperature, and labor to be average in price. Both plants are to run 24 hrs. a day, 365 days in the year, and are to carry at least 20% load-factor. Each plant will be assumed to have a reserve unit of .5 the total capacity of the plant. It will be understood that the term "load-factor" will here be used to mean the fraction (100% × total kws. per 24 hrs.) ÷ rated kws., assuming continuous operation of the plant throughout the 24 hrs. Under these conditions a low load-factor denotes a high fuel consumption.

The gas-driven plant requires 3 tandem, 4-cycle, double-acting 500-kw. units, with generators, producers, and auxiliaries. In the case of the steam plant, we can assume the exhaust turbine to be capable of delivering 80% of the rating of the non-condensing engine serving it. Hence, a 550-kw. compound Corliss engine and generator delivering all of its exhaust steam to a low-pressure turbo-generator of 450-kw. capacity meets the requirements of the 1000-kw. output. The turbine may be a balanced double-flow reaction machine, or, as the exhaust areas are comparatively small for this sized unit, it may be built single-flow and fitted with balancing pistons. The mixed-flow impulse type, being provided with high-pressure nozzles for admitting boiler steam when overloaded, is also well fitted for this class of work. The turbine may serve a separate circuit, in which case a governor and live steam connection with the boiler are required, or it may run in electrical unison with the engine, obviating the necessity for independent governing mechanism. At times of low load the engine can be connected directly to the condenser and the turbine cut out if both engine and turbine are on the same circuit, or if the circuit that the turbine serves does not require current at such times. A reserve duplicate Corliss unit is an ample safeguard against shut-downs, as in case of injury to the turbine the 2 engine units can carry the load, or, if either engine is out of commission, the other may be run in conjunction with the turbine.

The producer equipment of the gas plant will consist of 3 individual units, fitted with suitable scrubbers, superheaters, tar-extractors, and such auxiliaries, and may be either of the up or down-draft type. No attempt has been made to consider a by-product recovery plant of the Mond type, as the total amount of coal burned at full load would be less than 21 tons per day, a tonnage entirely too small for economic operation by the Mond system.

The maximum boiler capacity of the steam plant will be that required when the turbine and condenser are shut down and both engines operated non-condensing. Assuming a maximum water rate of 29 lbs. per kw.-hr. under these conditions, the plant output of 1000 kws. will require 29,000 lbs. of steam per hr. of 900 b.h.p. As maximum economy is not a necessity when the plant is run by the engines only, 3 225-h.p. units, driven ⅓ above rating, will supply the required amount of steam. Hence, allowing one standby unit, the boiler equipment of the steam plant may consist of 4 225-h.p. horizontal front-fired water-tube units, with economizers, stokers, internal superheaters, feed pumps, and the usual equipment. The

advisability of superheat in a plant of this size may be questioned, but as it serves to deliver dry steam to the turbine and obviates the necessity of steam separators in the exhaust line of the engines, its use is perfectly rational and the efficiency of the plant will be improved by its employment. A centrifugal jet condenser with rotative dry-air pump or a barometric tube may be employed to produce the necessary turbine vacuum of 28 ins., either of these types of condenser being efficient and moderate in price.

The 2 Corliss compound engines, 3-phase generators, exciters, switchboard, boilers and auxiliaries will cost about $88,000, or $80 per kw. The turbo-generator, with its condenser and auxiliaries, will cost about $22,500, or $50 per kw., making the total cost of the steam plant machinery $110,500. The cost of the 3 4-cycle gas engines with 3-phase generators, exciters, switchboard, air starting apparatus and gas generating plant will amount to about $142,500, or $95 per kw. The cost of buildings or foundations is not included in either of these estimates.

A day engineer at $4 and a night engineer at $3, with two helpers at $2 and two firemen at $2, are required for either plant, making the total labor expense for the 24 hrs. $15. Oil, waste and supplies have been charged at $5 in each plant.

TABLE XLVII. COSTS AND INTEREST OF STEAM AND GAS PLANTS

	Steam plant	Gas plant
Two 55-kw. engine units with generators, boilers and all steam and electric auxiliaries	$88,000.00	....
One 450-kw. exhaust turbine with generator, condenser and other auxiliaries	22,500.00	....
Three 500-kw. engine units with generator, producers and all gas and electric auxiliaries	....	$142,500.00
Total cost of plant	$110,500.00	$142,500.00
Interest at 5%	5,525.00	7,125.00
Depreciation, maintenance and repairs at 10%	11,050.00	14,250.00
Attendance of plant at $15 per 24-hr. day for yr. of 365 days	5,475.00	5,475.00
Oil, waste, etc., at $5 per 24-hr. day for yr. of 365 days	1,825.00	1,825.00
Total cost per yr., exclusive of fuel	$23,875.00	$28,675.00
"Plant charge," i.e., hourly cost, exclusive of fuel	$2.725	$3.273

In Table XLVII interest has been computed at 5%, and depreciation, maintenance and repairs charged to both plants at the rate of 10%. This 10% charge includes an 11% charge for depreciation, maintenance and repairs of the engines and boiler plant and a 6 per cent. charge for depreciation, maintenance and repairs of the turbine, the latter charge being relatively smaller because no boiler costs are entailed by its use, except when the live steam connection is employed in cases of emergency or severe overload.

It will be seen from Table XLVII that there is a constant hourly charge of $2.725 against the steam plant and of $3.273 against the

gas plant, whether the load-factor be high or low. This constant cost may be designated as the "plant charge" to differentiate it from the various items of fixed charges and from the total power cost. At low loads there would be a slight decrease in the cost of waste, lubricants, and such supplies, and consequently in the "plant charge," but as this would affect each plant equally it has not been considered.

To determine the relative cost of fuel per kw.-hr. the two curves in Fig. 52 have been plotted, showing the coal consumption, including standby losses, of the two plants at different loads. The curve of coal consumption for the steam plant is based upon an actual evaporation in service of 8 lbs. of water per lb. of coal burned, and on an assumption of 165 lbs. initial pressure expanding to 17 lbs. in the engine and to 28-in. vacuum in the turbine, allowing 1-lb. pressure drop between the engine and turbine, as recommended by J. R. Bibbins, in his paper before the Canadian Society of Civil Engineers, Nov. 26, 1908. An engine working through such a

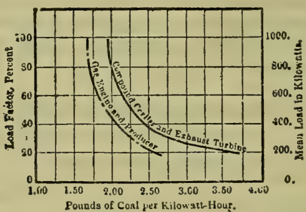


Fig. 52. Cost of coal for the plants.

pressure range may be expected to give good economy and the allowance of 1-lb. drop between engine and turbine obviates the injurious effects upon the engine of a variable back pressure due to the turbine. In plotting the curve of coal consumption for the gas plant, it has been assumed that the load carried is of a violently varying nature, with severe peaks, such as are met with in electric railway work or in rolling mills; hence 2 units must be kept in use for the greater part of the time. Where the low load-factor is caused by a steady light load, with a heavy peak of short duration, the coal consumption shown by this curve can be decreased by running one unit only when the load falls off. In large stations with a number of individual units, light loads would not cause the great increase in fuel per kw.-hr. indicated by these curves, as the load could be divided between a few machines and these driven at full load, so that the loss in economy would be small, being principally due to the banking of the extra boilers or producers.

The cost per kw.-hr., exclusive of the fuel charge, may be determined for any particular load-factor by dividing the plant charges $2.725 and $3.273 by the load carried in kws. This quotient of plant charge divided by load, added to the cost of coal per kw.-hr. at the load-factor investigated gives the total expense of generating

one kw.-hr., and a curve may be drawn showing the relation of this total cost to the load-factor. In Fig. 53 curves have been plotted for the two plants, showing the increase of cost per kw.-hr. with loads ranging from 1000 to 200 kws. The pounds of coal per kw.-hr. used in determining the fuel cost at various loads are those shown by the curves in Fig. 52. Coal is assumed to be worth \$3 per ton of 2000 lbs.; plant charges to be \$2.725 and \$3.273 an hr. A glance at these two curves shows that with \$3 coal the steam plant is the more economical at every stage of load above and including 200

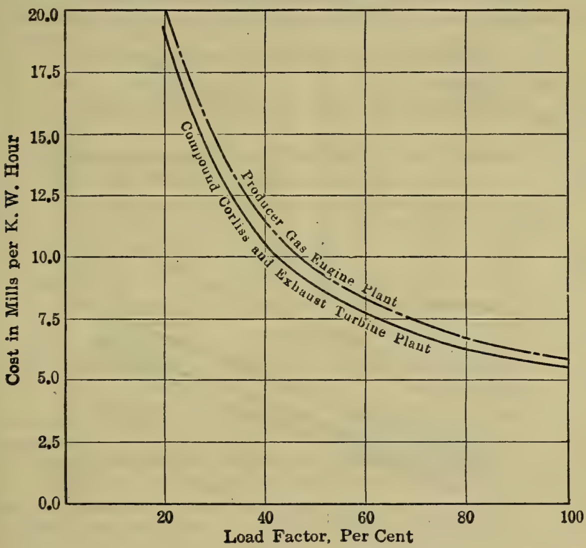


Fig. 53. Increase in cost with different load factors.

kws., the lowest load considered, and that the difference in cost per kw.-hour increases as the load-factor grows smaller.

The curves of Fig. 54 illustrate the effect of the price of coal on the cost per kw.-hr., the load-factor being assumed to be constant for each pair of curves drawn. These curves are all straight lines and they show that the greatest difference in cost exists at the lowest price of coal, the steam plant curve approaching that of the gas plant as this price increases. At the coal cost per ton corresponding to the intersection of these curves, both stations are of equal economy. At any price of coal greater than this "critical" price, the gas plant is the more economical; at any price less, the steam plant.

The cost of the foundations for the turbine and engines of the steam plant will be much less than the cost of those upon which

the 3 gas-engine units are erected, and will offset to some extent the increase in cost of the boiler foundations, settings, chimney, and such equipment, over that of the foundations required by the producers, scrubbers, and auxiliaries, of the gas-driven station. The total floor space occupied by the 2 Corliss engines, at 2.3 sq. ft. per kw., will be about 2800 sq. ft., and, allowing 2.6 sq. ft. per b.h.p., the station area exclusive of turbine will be about 5100 sq. ft. Assuming that the turbo-generator and electrical equipment do not require more than 900 sq. ft., the total area of the plant, without office or shop, will be in the neighborhood of 6000 sq. ft. The area of the engine-room of the gas plant, at 3 sq. ft. per kw., will be

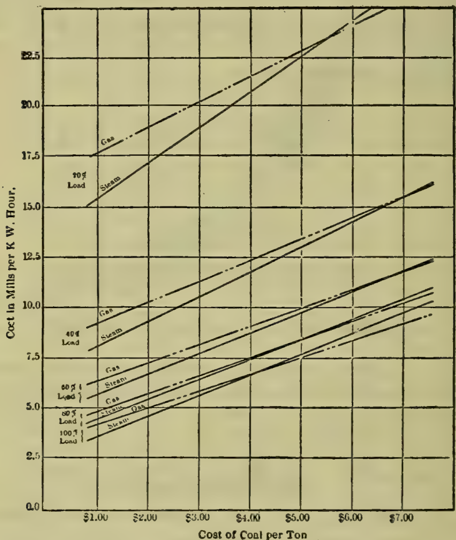


Fig. 54. Effect of cost of coal on power cost.

4500 sq. ft. and that of the producer, at 1.5, 2250, making the total plant area, exclusive of office or shop, approximately 6750 sq. ft. In Fig. 55 a layout of each plant is shown, planned without provision for high-tension apparatus. The producer room of the gas plant contains a compressor and starting tanks, and a small fan for blowing up the producers when cold; both auxiliaries are driven by a small oil engine. Steam is supplied to the jet blowers of the producers by a waste-heat boiler utilizing the engine exhaust. Duplicate exciters, driven by separate engines, are provided, one being held as a reserve. The engine-room of the steam plant is also equipped with exciters in duplicate, one being direct-connected

to the turbine and used to excite both generator fields when the turbine is in use, and the other being engine-driven and used when the turbine is closed down. As there is little waste steam available for heating the feed-water, the condenser auxiliaries being electrically driven, the boilers are equipped with economizers.

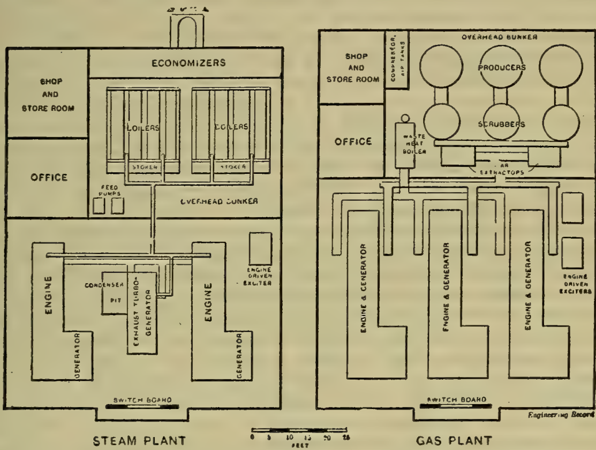


Fig. 55. Proposed arrangement of steam and gas plants.

In Table XLVIII the total costs per yr. of 8760 hrs. have been computed for each plant, the price of coal being assumed to be \$3 a ton and fixed charges, insurance and taxes on buildings and land not considered. Although the difference in cost per kw.-hr. is greatest at 20% load-factor, it will be seen from this table that the greatest saving per year is at a factor of 40%.

TABLE XLVIII. TOTAL COSTS PER YEAR, EXCLUSIVE OF FIXED CHARGES, INSURANCE AND TAXES

Load-factor	Steam plant	Gas plant	Difference
100%	\$49,756.80	\$51,009.48	\$1,252.68
80%	44,893.25	46,750.37	2,057.12
60%	40,429.15	43,020.36	2,591.21
40%	36,749.95	39,497.09	2,747.14
20%	33,412.39	35,504.28	2,091.89

If cheap condensing water is not plentiful and cooling towers are employed, an increase of about \$4,000 must be charged against the first cost of the steam plant. The difference in the cost of buildings, foundations, and other structural features will not exceed \$6,000, and this, with the cost of the cooling towers, will make a debit of \$10,000 against the steam plant on which about 10%, or

$1,000 a year, must be charged. Thus, under unfavorable condensing conditions, the steam plant still shows a saving of $252.68 at 100% load-factor, the most advantageous factor at which the gas plant can operate.

It may be argued that the gas producer will show better relative economy compared to the steam boiler, when low-grade fuels are used, than the curves in Fig. 52, which were plotted for good steam coal, would indicate. At the Government fuel testing station in St. Louis it was found that the fuel consumption of a comparatively small producer plant increased from 2 to 4.5 lbs. per kw.-hr. when the heat value of the fuel decreased from 14,000 B.t.u. to 6500 B.t.u. It may reasonably be claimed that no coal-fired boiler plant could give such efficiency on fuels that are so low in thermal units; but if the boilers be fired with producer gas this objection is no longer valid, as they will then deliver practically the same efficiency with fuels varying widely in thermal value. As Mr. Ernst Schmattolla observes in an article on Gas-Producers and Gas-Firing, in The Mining Journal, London, Feb. 6, 1909, a far more complete combustion may be attained with gas-firing than by either hand or automatic stoking, the smoke nuisance eliminated and an excess of air in the furnace avoided. A small thermal loss must inevitably occur when producer-gas is passed through scrubbers for purification and cooling, preparatory to its use in an engine cylinder, for it is virtually impossible to utilize all of the sensible heat of the gas in superheaters or boilers, and that abstracted by the scrubbing apparatus is thrown away. This loss does not occur in the gas-fired boiler, since the gases are delivered directly to the combustion chamber through a short flue and in a highly heated state. Practically all the heat radiated from the combustion chamber is taken up by the incoming air, which forms an air-jacket about it. The cost of such a producer, having no scrubbers or tar extractors, would be largely offset by the cost of the automatic stoking apparatus required for firing the ordinary boiler furnace.

No discussion of this subject would be complete without reference to the comprehensive paper of Mr. H. G. Stott, Notes on the Cost of Power (given later in this chapter), printed in the April, 1909, Proceedings of the A. I. E. E. It is illustrated by more than 20 cost and load curves of representative power plants of various types. From these data it would seem that, aside from hydraulic installations, the most economic type for ordinary load-factors is one in which gas engines are used to take the low load portion of the curve, assisted by steam turbines in carrying the peak. It should be remembered, however, that Mr. Stott deals with station capacities of not less than 30,000 kws. and the inferences drawn from plants of this size may not entirely be applicable to small installations consisting of a few relatively large units, for the latter must run at low load when the load-factor drops, with correspondingly high fuel consumption. Of course, it is obvious that in a majority of reciprocating engine plants running on bituminous coal, the addition of exhaust turbines may be a better

method of improving the station economy than the abandonment of steam and the installation of a producer-gas plant.

Cost of Power in Gas Producer Plants versus Steam. Julius I. Wile gave Tables XLIX-LIII in a paper read before the Technology Club of Syracuse, N. Y., which were afterward published in Power, April, 1906.

The figures from Tables XLIX and L are from actual tests, with the exceptions that where these units in a pound of coal were not given in the reports they have been assumed, 12,500 and 13,600 B.t.u. per pound respectively.

The main characteristic difference between the pressure producer and those of the suction type is that in the former the complete system is under pressure, supplied by a steam jet blower or a power driven fan, a gas holder being necessary for storing the gas and also an independent boiler necessary to raise the steam for saturation and for the blower. In the suction type the gas is pulled by the suction of the engine, both holder and independent steam boiler being eliminated, steam and atmospheric pressure necessary for saturation in the generator being raised by the passage to the cleaning apparatus of the hot gases from the generator. The space occupied by the suction type is less than the other and is also less than that required by a return tubular boiler of the same power. Advantage is also added by the fact that the attention required by the station force is also considerably less than in the case of the pressure type.

Pressure producers must be fed once every half hour unless automatic feeds are installed, since the level of the fuel must be fixed to obtain constant resistance, this being only necessary once in 3 hours at full load and once every 5 hours at half load in suction producers which are fitted with large fuel reservoirs. For this latter type, Mr. Wile says that, the total attention otherwise required for starting up in the morning is 15 mins. and 20 mins. at night.

In the Dowson type of pressure plant, the best known example of which is the one at Walthanstow, London, England, an independent boiler supplies the pressure by a steam blast. The 3000-h.p. plant of this type, quoted in Table XLIX, comprised 8 Dowson generators and 13 direct-coupled vertical engines. The generating costs given in Table LI include fuel, supplies, labor and repairs, in comparison with an average of 11 steam plants, having about 3 times the output of the Dowson plant. Under the high costs of coal and water in the London district this Walthanstow plant shows a saving of 38% in fuel and 21% in operating cost. If the fuel costs for the compared plants were the same the Dowson type would show a fuel saving of 51% and operating saving of 29%.

In Table LII these figures are somewhat bettered, for comparative plants in Guernsey, England, where the gas is 58% in fuel and 48% in operating cost.

The Taylor producer on which the U. S. Geological Survey tests at St. Louis were made in 1905 are mentioned in Table XLIX is here compared with the Wilson producer, which is of the Dowson

TABLE XLIX. THERMAL EFFICIENCIES OF GAS ENGINES AND PRESSURE GAS PLANTS

Brake h.p.	Type of producer	Type of engine	Fuel	B.t.u. per lb.	Fuel consumption lb. per b. h.p. Producer	Boiler	Total	Thermal efficiency %
250	Taylor	Westinghouse 3 cylinder	Colorado Bituminous	9,767	1.66	.29	1.95	13.40
250	Wilson	Stockport single cyl.	Bituminous	12,500	1.26	.14	1.4	14.6
280	Dowson	4 cyl. vert. Campbell	Anthracite	13,600	.99	.13	1.12	16.50
3000	Dowson	Westinghouse 3 cylinder	Anthracite	13,600	1.07	.13	1.20	15.60

TABLE L. THERMAL EFFICIENCIES OF GAS ENGINES AND SUCTION GAS PLANTS

Brake hp.	Type of engine	Fuel	B.t.u. per lb.	per b. h.p. Lb: of fuel	efficiency % Thermal
20	National; single cylinder	Anthracite	15,138	.797	21¼
90	Crossley; single cylinder	Coke	12,411	.91	22½
250	Deutz; double acting	Anthracite	14,600	.744	23⅓
300	Crossley; two cylinder	Anthracite	11,370	.975	24

TABLE LI. COMPARATIVE TESTS OF STEAM AND PRESSURE GAS POWER PLANTS IN THE LONDON DISTRICT

	Kws. capacity	Output units	Load factor %	Cost of fuel per ton	Cost per unit, cts. Fuel	Sup'l's	Labor	Rep'rs	Total
Average of 11 Steam Plants	2799	2,987,500	17.25	$5.00	1.194	0.118	0.418	0.436	2.176
Pressure Producer Gas	810	1,019,326	15.45	6.75	0.736	0.304	0.576	0.096	1.712
Difference	—1989	—1,978,174	— 1.80	+$1.75	—0.458	+0.186	+0.158	—0.340	—0.464

TABLE LII. COMPARATIVE TESTS OF GAS AND STEAM PLANTS AT GUERNSEY, OF 180 KWS. CAPACITY, COVERING PERIOD OF ONE MONTH

	Kws. capacity	Output units	Load factor %	Cost of fuel per ton	Cost per unit, cts. Fuel	Sup'l's	Labor	Rep'rs	Total
Steam Plant	180	55,108	45.6	$4.20	1.178	0.156	0.284	0.512	2.130
Gas Plant	180	50,361	65.8	4.43	0.496	0.096	0.304	0.208	0.104
Difference		—4,847	—20.0	—$0.23	—0.682	—0.060	—0.020	—0.304	—1.026

pressure type. Mr. Wile says that the main reason why the Taylor plant is not as efficient as the Wilson one is on account of the scrubbing device being of the rotary type requiring power, while Wilson uses the stationary type of scrubber. He gives the efficiency of these types of producer at from 60 to 65%.

A radical difference in the character of the anthracite coal found in America and Europe accounts for the necessity of different distinctive features between the successful suction gas producers in the two countries. The American coal has not as great a heat value as the European, is not as free burning, has a larger percentage of ash with a tendency to clinker, which combination makes it necessary for the fuel beds of American producers to be larger in area per unit of power than those employed abroad, and also necessitates the use of shaking grates and poke holes.

Producer gas is the result of incomplete combustion of fuel, due to the absence of sufficient oxygen to support combustion, and for its formation a deep fuel bed is essential. An ordinary blast furnace is an ideal form of gas producer, as the body of coal or coke is subjected to a blast of air beneath the fuel bed and without any provision above for the product of combustion, carbon monoxide, to burn to carbonic acid gas (CO_2). The gas arising from a blast furnace has a heat value of approximately 90 B.t.u. per cu. ft.

As an idea of the power which goes to waste in blast furnaces, it should be borne in mind that from every ton of pig produced before the waste gases have been used to heat the air blast, there is available in the waste gases the heat equivalent of 600 h.p.-hrs. For doing the work of the blast furnace about 240 h.p.-hrs. are necessary, which leaves 360 h.p.-hrs. available for other purposes. To make this gas suitable for use in a gas engine, it must be cleaned of all impurities, and a cleaning apparatus is common to all forms of gas producers for supplying engines. It has been found, however, that on account of the minute particles of dust and the different classes of iron as well as coke or coal which are used in the blast furnace, a cleaning apparatus suitable for one class of gas is not always suitable for another.

Table LIII shows the various kinds of gases which are used in gas engines, showing their heat value and chemical composition by volume.

TABLE LIII. COMPOSITION OF GASES

Kind of Gas	H	CH_4	C_2H_4	O	CO_2	N	B.t.u.
Blast Furnace Gas	1	..	..	25	12	62	90
Producer Gas from Anthra. ..	12	1.5	..	27	3.5	57	140
Producer Gas from Bitum. ..	10	6.5	..	15	10	58.5	150
Blue Water Gas	44.5	..	..	42	3.5	10	295
Coke Oven Gas	39	40	5	5	3	8	660
Coal Gas	45	38	6	6	1	4	720
Natural Gas	2	95	..	..	..	3	1020

Another type of gas producer is the by-product coke oven. In coking one long ton of coking coal in a retort, there are generated 8,000 to 10,000 cu. ft. of gas carrying from 60 to 100 lbs. of tar

and 10 to 20 lbs. of ammonium sulphate. The sale of these products usually covers the cost of their extraction and the gas, which is approximately 600 B.t.u. per cu. ft., is required for carrying on the coking process, so that from one ton of coal there are available about 200 effective h.p.-hrs.

Producer gas has a calorific value of approximately 140 B.t.u. per cu. ft., depending upon the type of producer. With different types of producers there are larger or smaller percentages of CO_2, CO and hydrogen, but the general average of the gas is approximately as stated.

Comparative Costs of Power by Diesel Engine and Steam Turbine in Plants of 600 kw. Capacity. The following, Electrical World, Oct. 9, 1915, is from papers read by A. H. Goldingham and W. H. Adams, at the Panama-Pacific Exposition meeting of the A. S. M. E.

TABLE LIV

Assumptions: Load-factor, 25%; maximum load equal to rated output. (This gives turbines slight advantage in overload capacity.) Turbines operated condensing, using jet condenser and cooling tower. Oil fuel. Crude oil, 95 cts. per barrel; distilled oil, $1.50 per barrel. Turbine plant develops 140 kw.-hr. per barrel. Diesel plant develops 447 kw.-hr. per barrel.

FIRST COST

Turbine plant 1 200-kw., 1 400-kw. units		Diesel-Engine plant	1 200-kw., 1 400-kw.	3 200-kw. units
Boilers and settings	$6,200	Engines	$51,000	$47,500
Pumps	250	Erecting	5,000	5,000
Piping	500	Piping	1,400	1,400
Stack and flues	2,950	Oil tanks	1,000	1,000
Heaters	500	Water-cooling apparatus	1,000	1,000
Turbines	12,500	Generators	11,400	11,400
Generators, etc.	11,400	Building	6,000	6,000
Condensers	2,400			
Cooling tower	3,500			
Building	10,000			
Total	$50,200	Total	$76,800	$73,300

OPERATING COSTS (1,314,000 KWS. PER YEAR)

Turbine plant		Diesel-Engine plant	
Wages	$3,000	Wages	$3,000
Lubrication	500	Lubrication	500
Miscellaneous	100	Miscellaneous	100
Maintenance	400	Maintenance	400
Water	250	Water	50
	$4,250		$4.050

			3 engines	2 engines
Fuel, 95 cts. bbl.	$8,910	Fuel, 95 ct. bbl.	$2,790	$2,790
Fixed charges 14%	7,030	Fixed charges, 14%	10,780	10,280
Total	$20,190	Total	$17,620	$17,120

The plants quoted are imaginary, but the cost figures are believed to be approximately correct.

According to these curves when the price of oil is about 53 cts. a barrel, the yearly cost will be the same for both of the plants considered. At this price the Diesel plant has the advantage. The

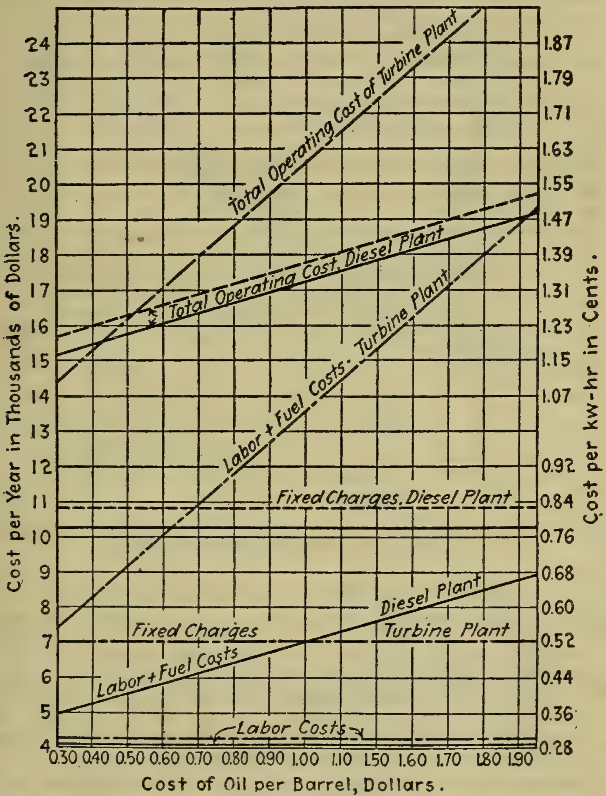


Fig. 56. Comparison of operating expenses of 600-kw. steam turbine and Diesel-Engine plants.

output for a barrel of oil is based on reports from both Diesel and steam plants, the oil engine plant being in Texas and the steam plant in California. Operating expenses also are based on reports from these two plants.

Cost of Power in a 700-kw. Gas Electric Plant and a Comparison

Between That and the Estimated Cost in a Steam Turbine Plant. The following data are abstracted from a paper by J. R. Bibbins, appearing in the July, 1908, Proceedings of the A. I. E. E.

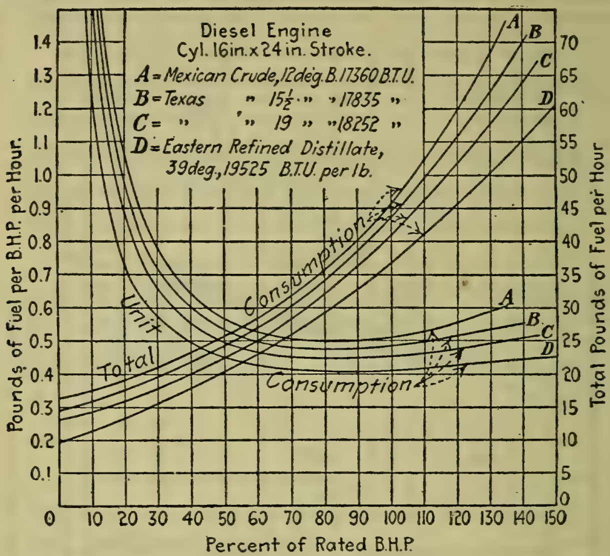


Fig. 57. Unit and total fuel consumption for Diesel Engines at different percentages of rated load.

COST OF POWER, 700-KW. GAS POWER PLANT: —

Equipment cost: Building and machinery, $138 per kw., $96,600.
Fixed charges: Int. 5%, taxes and insurance 1.5%, depreciation (sinking fund 15 yrs. 5%) 4.63%, running repairs 1.5% on investment. Total 12.63% per yr., $12,220.
Operation: 300 days, 7200 hrs. per yr., 5,040,000 kw.-hrs. Input to auxiliaries, 5.4% full, 10.8% half-load. Standby losses, producer plant, 1600 lbs. per week, 2.1% full, 3.1% half-load. Fuel rate, full load, 1.59 lbs. + 2.1% = 1.62 lbs. per kw.-hr.; half-load 2.1 lbs. + 3.1% = 2.17 lbs. per kw.-hr.

ESTIMATED COST OF POWER, WITH SAME CONDITIONS FOR A 700-KW. TURBINE

Equipment cost: Building and machinery, $100 per kw., $70,000
Fixed charges: Int. 5%, taxes and insurance 1.5%, depreciation (sinking fund 16⅔ yrs. at 5%) 4%; repairs 1%, total 11.5%, $8,050.
Operation: 300-day yr., 7200 hrs.; average water rate, full-load 21.5 lbs. per kw.-hr., average water rate, half-load 25.5 lbs. per kw.-hr.; gross evaporation, 7.5 to 8.0 lbs.; standby, banking 10 to 15%; gross coal consumption, full, 2.96 lbs. per kw.-hr., half, 3.9 lbs. per kw.-hr.
Wages and supplies — Same as gas.

The following figures were obtained as a result of tests made at the Richmond plant of the American Locomotive Company and described in the Proceedings of the A. I. E. E. for the 25th Annual Convention by J. R. Bibbins. The equipment comprised the main service plant of the Richmond Works and included a 23.5 by 33 in. horizontal, tandem gas engine, with direct connected d.c. generator, operating on producer gas generated by a pair of 9-ft. (shells) bituminous producers, a 15,000 cu. ft. holder serving to equalize its quality and to start the engine, of the double-acting type with two impulses per revolution, governed by a sensitive oil relay system designed to relieve the governor of all valve work. The gas was purified by means of wooden slat scrubbers and centrifugal tar extractor, motor-driven. The producer was designed for continuous operation, having a water-sealed bottom to permit the removal of ash at any time. It generated its own steam, the only auxiliaries required for the entire plant being a motor-driven fan, tar-extractor, and igniter set, these absorbing about 5% of the station capacity. The test was continued for about 4 weeks, part of the time on a full-load run, the remaining two weeks at .75 and .5 loads respectively, with a rate of gasification of .25 ton per hr.

TABLE LV. TESTS OF A GAS-ELECTRIC PLANT

Nominal load	Full	Three-quarters	One-half
Length of run, hrs.	223	125	136
Average load, kws.	312.3	228.3	159.6
Average load, computed boiler h.p.	455.0	333.0	238.0
Load, %, engine rating	91.0	67.6	47.5
Load, %, generator rating	104.0	77.2	53.2
Coal gasified, lbs.	115,289	54,143	47,775
Coal gasified, per hr.	517.0	433.0	351.0
Output, kw.-hrs.	69,650	28,540	21,710
Lbs. coal per kw.-hr.	1.654	1.697	2.20
Lbs. coal per kw.-hr., guaranteed	1.93	2.10	2.64
Lbs. coal per b.h.p.-hr.	1.14	1.31	1.56
Avg. heat value of coal, B.t.u.	14,392	14,392	14,392
B.t.u. per kw.-hr.	23,700	27,280	31,650
B.t.u. per b.h.p.-hr.	16,415	18,710	21,670
% thermal efficiency, brake	15.51	13.6	11.75
% thermal efficiency, elec.	14.35	12.65	10.78

Coal.— Pocahontas, run-of-mine; avg. heat value; dry sample, 14,703; as fired, 14,392; volatile matter, 22.8%; ash, 4.5%; sulphur, 1%. Test.— August 12, 7 A. M., to September 7, 12 M.

These data are shown plotted in Fig. 58 in 3 curves as follows: (a) rate of gasification in lbs. per hr.; (b) lbs. per unit of output per hr., and (c) corresponding thermal efficiency. This last is absolute or kinetic efficiency, and covers all losses between coal pile and switchboard.

Operating Conditions. The plant normally operated at 24 hrs. per day at practically full load. It has sustained a load of 410 kws. or 19% overload on the engines for 3 hrs., and higher overloads than this for short periods. The electrical rating of the plant was figured at 700 kws., giving it an investment cost of about $138

per kw. complete including machinery, buildings, foundations, piping, erection, etc., except the value of the land occupied.

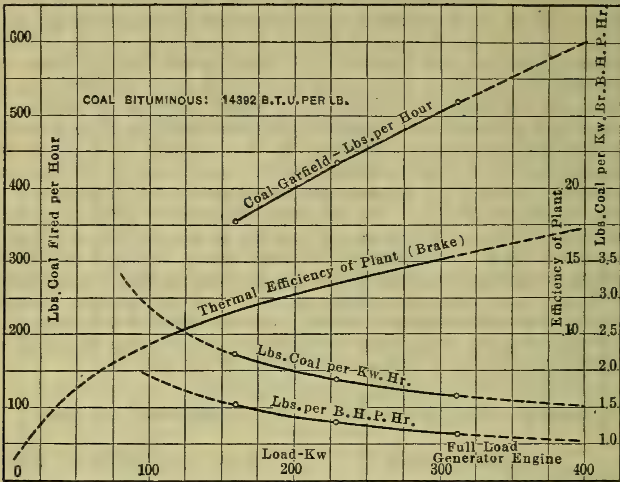


Fig. 58. Gas power plant economy at various loads.

TABLE LVI. UNIT COST PER KW. AND H.P.-YR., FOR THE GAS PLANT

		Full load	Half load
		Cts. per kw.-hr.	
Coal	at $1.00	0.081	0.109
	2.00	0.162	0.217
	4.00	0.324	0.434
	6.00	0.486	0.651
Wages	per year, $6,160	0.121	0.242
Supplies	" 3,850	0.076	0.143
Fixed charges	" 12,200	0.242	0.484
Total costs — coal at	$1.00	0.520	0.978
	2.00	0.601	1.086
Richmond coal	2.70	0.658	1.163
	4.00	0.763	1.303
	6.00	0.925	1.520
Equivalent power rate:		Dols. per electric h.p.-year	
300-day year, coal at	$1.00	$27.90	$52.40
	2.00	32.30	58.20
	2.70	35.60	62.40
	4.00	41.00	69.90
	6.00	49.60	81.50
Charges for auxiliaries if motor-driven		2.7%	7.4%
Saving gas over steam, %:			
Coal at	1.00	—3 loss	—8.5 loss
	2.00	+8 gain	+0.9 gain
	2.70	12.9 "	4.7 "
	4.00	19.6 "	12.4 "
	6.00	33.7 "	19.0 "

This is based on 300-day operation, 7200 hrs. per yr., the fixed costs being distributed over the operating period, and unit prices being figured for various prices for coal, which prices are based upon a net ton.

The price of fuel at Richmond was $2.70, at which basis the power could be delivered at the switchboard for ⅔ ct. per kw.-hr. at full

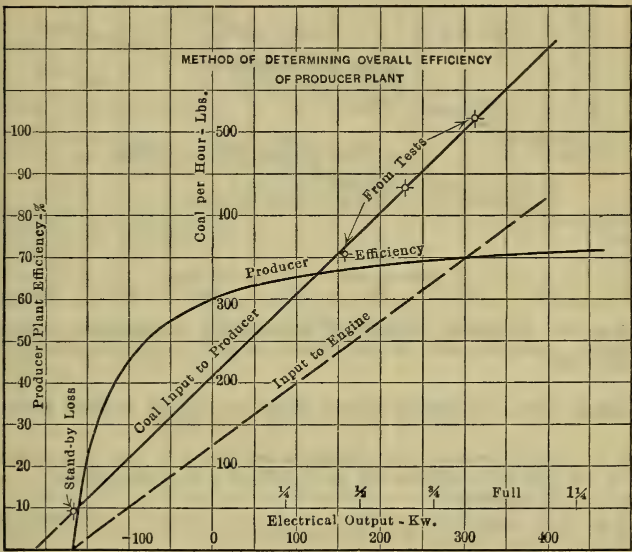


Fig. 59. Graphical method of determining over-all efficiency of producer plant.

load operating 7200 hrs. per yr., or about 1.25 cts. at half load, taking into account fixed charges which amount to about 40% of the total cost.

Relative Cost of Gas and Steam Power. This is shown by Fig. 60 showing the comparative cost for Richmond conditions.

At the price of coal in Richmond, the gas plant showed 13% gain over steam at full load and 5% at half load. Thus with steam coal at $2.70, cost by steam power would be about the same as if bought by the gas plant if the gas plant paid $4.00 for gas coal. The gas plant is at a disadvantage, however, for light loads or fluctuating loads averaging a small fraction of the generating capacity.

Comparative Costs of Installation and Operation of Gas, Oil and Steam Engines. R. E. Mathot gave the following data in Power,

March 5, 1912, based on normal figures for labor, fuel consumption, etc., for Belgium in 1912.

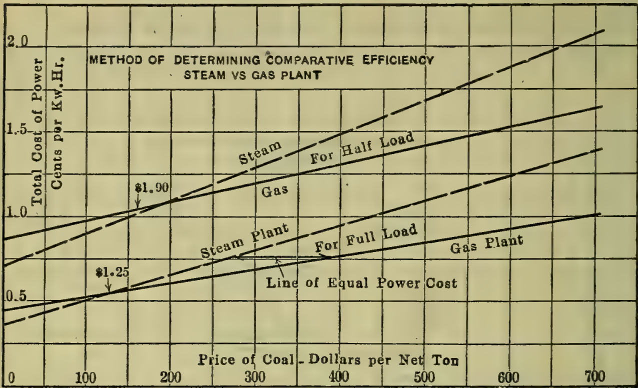


Fig. 60. Graphical method of determining comparative cost efficiency, producer gas versus steam turbine plant for Richmond conditions.

TABLE LVII. COMPARATIVE INSTALLATION COSTS FOR A POWER PLANT OF 3000 H.P.

FOR A FACTORY UTILIZING AN AVERAGE OF 2000 H.P. AND A MINIMUM OF 800 H.P. DURING 300 DAYS PER YR., 24 HRS. PER DAY

Diesel-type Engines	
4 800-h.p. engines at $29,000	$116,000
Foundations, pipings and connections	4,000
	$120,000
Suction Producers and Engines	
5 600-h.p. engines at $13,200 and 10 300-h.p. producers at $2,000	$86,000
2 spare producers	4,000
Foundations, pipings and connections	6,000
	$96,000
Semi-portable Steam Engines	
5 600-h.p. engines at $17,000	$85,000
Masonry, connections and stacks	3,000
	$88,000
Turbo-alternators	
3 750-kw. units at $16,600	$49,800
Foundations and piping	3,000
8 Lancashire boilers, 1300 sq. ft. of heating surface each	16,000
Masonry for boilers	2,800
Flues and stacks	1,400
Automatic stokers	2,400
Superheaters	3,200
	$78,600

Piston Steam Engines

2 1,500-h.p. engines	$30,000
Foundations and connections	5,000
7 boilers of 1,300 sq. ft. heating surface each	14,000
Masonry for boilers	2,400
Flues and stacks	1,200
Automatic stokers and heaters	4,800
	$57,400

COMPARATIVE ANNUAL LABOR COSTS

Crude-oil Engines

Four engines require 2 engineers at 13 cts. per hr.		$0.26
3 laborers at 6 cts. per hr.		0.18
Total		$0.44
Per yr.: 300 days × 24 hrs. × $0.44	$3,168	

Fuel-gas Engines

Five engines require 3 engineers at 13 cts. per hr.		$0.39
5 stokers at 9 cts. per hr.		0.45
5 laborers at 6 cts. per hr.		0.24
Total		$1.08
Per yr.: 7,200 × $1.08	$7,776	

Semi-portable Engines

Five engines require 3 engineers at 13 cts. per hr.		$0.39
5 stokers at 10 cts. per hr.		0.50
5 laborers at 6 cts. per hr.		0.30
Total		$1.19
Per yr.: 7,200 × $1.19	$8,568	

Turbo-Generators

Three engines require 2 engineers at 15 cts. per hr.		$0.30
2 stokers at 10 cts. per hr. (the boilers are provided with automatic stokers)		0.20
3 laborers at 6 cts. per hr.		0.18
Total		$0.68
Per yr.: 7,200 × $0.68	$4,896	

Piston Steam Engines

Two engines require 2 engineers at 13 cts. per hr.		$0.26
2 stokers at 15 cts. per hr. (automatic coal feeders)		0.20
3 laborers at 6 cts. per hr.		0.18
Total		$0.64
Per yr.: 7,200 × $0.64	$4,608	

ANNUAL EXPENDITURE FOR FUEL

AVERAGE LOAD, 2,000 H.P. DURING 300 DAYS OF 24 HRS. EACH, GIVING 2,000 × 24 × 300 = 14,400,000 BRAKE HORSE-POWER-HOURS PER ANNUM

	Per Year
Diesel-type Engines	
Consuming about 200 gr. of crude oil per brake horse-power-hour. Russian or Texas oil costs $1.40 per 100 kg., giving a cost of $.28 ct. per b.h.p.-hr. or $0.0028 × 14,400,000 =	$40,493

Producer Gas Engines

Consuming at variable load per b.h.p.-hr. 400 gr. of lean coal, which costs \$3 a ton, or 12 cts. per b.hp.-hr.; \$0.012 × 14,400,000 = ... \$17,280

Turbines

At variable load consuming about 6 kg. of steam per b.h.p.-hr., which gives a consumption per b.h.p.-hr. of 7.5 kg. of steam = 1 kg. of coal at \$3.20 a ton, or 0.32 ct. per b.h.p.-hr.; \$0.0032 × 14,400,000 = ... \$46,080

Semi-portable Steam Engines

Consuming per b.h.p.-hr. 520 grs. of semi-bituminous coal at \$3.20 a ton or 16.64 cts. per b.h.p.-hr.; \$0.1664 × 14,400,000 = ... \$23,962

Piston Steam Engines

Consuming 4.5 kg. of steam per i.h.p.-hr. or 5 kg. steam per b.h.p.-hr. With a normal evaporation of 7.5 kg. of steam per kg. of semi-bituminous coal, one b.h.p.-hr. requires 0.665 kg. of coal, at \$3.20 a ton, giving 21.28 cts. per b.h.p.-hr.; \$0.2128 × 14,400,000 = ... \$30,643

COMPARISON OF THE PRINCIPAL ANNUAL OPERATING COSTS

Type of equipment	Depreciation rate, %	Fixed charges[1]	Fuel	Attendance	Annual total
Diesel engines	15.5	\$18,600	\$40,493	\$3,168	\$62,261
Producer gas	15.5	14,880	17,280	7,776	39.936
Semi-portable steam	12.9	11,352	23,962	8,568	43.882
Turbines, etc.	12.9	10,139	46,080	4,896	61,115
Piston engines, etc.	11.2	6,486	30,643	4,608	41,737

[1] Depreciation plus 5% interest on investment.

Mr. Mathot took into account various factors derived from practice, determining the number of units necessary for realizing the 3000-h.p. maximum under consideration. These factors include reliability, margin of power, load variations upon the fuel consumption, facility of attendance, etc. He considered 4 Diesel engines, 3 of which would be running while, owing to the facility of starting, the fourth engine would be at standstill but ready for service. The producer-engine plant allows 5 units of 600 h.p. each, the power being easily realized from single-acting, twin two-cylinder engines connected by couplings, with the flywheel in the middle, this engine being cheaper to build, economical in up-keep and the attendance simpler than the double-acting type.

The figures were for suction producers rather than pressure ones, and Mr. Mathot allows 10 producers of 300 h.p. each, plus 2 generators which would constitute the spare apparatus.

The engines were calculated for a margin in power of 10 to 20%, and should develop the estimated 600 h.p. with a mean effective pressure on pistons of 65 lbs. per sq. in.

The figures on German semi-portable steam engines of the self-contained boiler and engine type, having a fuel consumption of less than 1 lb. of gross coal per b.h.p.-hr., with large power margin and without spare units.

For the other steam plants he assumes the installation of 1 or 2 additional boilers of the Lancashire type with 2 or 3 corrugated internal furnace tubes, and with evaporation rate of 3 to 3.5 lbs. of water evaporated per hr. per sq. ft. of heating surface or 8.5 lbs. of steam per lb. of good coal.

In considering depreciation, the Diesel engine may be considered on the same basis as fuel-gas engines of good construction, allowing 10 yrs. for amortization, while 15 yrs. is allowable for semi-portable steam engines and 20 yrs. for stationary steam engines of the Corliss, Sulzer and piston-valve types.

Repair costs are not considered.

Comparative Cost of Power in Small Units of Gasoline, Gas, Steam and Electricity. William O. Weber published the following data in Engineering News, Aug. 15, 1907.

COST OF GASOLINE POWER

Size of plant, h.p.	2	6	10	20
Price of engine in place	$150.00	$325.00	$500.00	$750.00
Gasoline per b.h.p. per hr.	⅓ gal.	¼ gal.	⅙ gal.	⅛ gal.
Cost per gal.	$0.22	$0.20	$0.19	$0.18
= cost per 3,080 hrs.	$451.53	$924.00	$975.13	$1,386.00
Attendance at $1 per day	308.00	308.00	308.00	308.00
Interest, 5%	7.50	16.25	25.00	37.50
Depreciation, 5%	7.50	16.25	25.00	37.50
Repairs, 10%	15.00	32.50	50.00	75.00
Supplies, 20%	30.00	65.00	100.00	150.00
Insurance, 2%	3.00	6.50	10.00	15.00
Taxes, 1%	1.50	3.25	5.00	7 50
Power cost	$824.03	$1,371.75	$1,498.13	$2,016.50

To these figures should be added charges on space occupied, as follows:

Value of space occupied	$100.00	$150.00	$200.00	$300.00
Interest, 5%	$5.00	$7.50	$10.00	$15.00
Repairs, 2%	2.00	3.00	4.00	6.00
Insurance, 1%	1.00	1.50	2.00	3.00
Taxes, 1%	1.00	1.50	2.00	3.00
Total annual charge for space	$9.00	$13.50	$18.00	$27.00
Total cost per annum	$833.03	$1,385.25	$1,516.13	$2,043.50
Cost of 1 h.p. per annum 10-hr. basis	416.51	239.87	151.61	102.17
Cost of 1 h.p. per hr.	$0.1352	$0.0780	$0.0492	$0.0331

COST OF ELECTRIC POWER

Size of plant, h.p.	2	6	10	20
Cost of motor in place	$83.00	$118.00	$216.00	$270.00
With wiring, etc.	100.00	130.00	240.00	300.00
Cost of electricity 3,080 hrs.	$529.56	$976.00	$1,425.00	$2,450.00
Attendance	20.00	30.00	50.00	50.00
Interest, 5%	5.00	6.50	12.00	15.00
Depreciation 10%	10.00	13.00	24.00	30.00
Repairs, 5%	5.00	6.50	12.00	15.00
Supplies, 1%	1.00	1.30	2.40	3.00
Insurance, 2%	2.00	2.60	4.80	6.00
Taxes, 1%	1.00	1.30	2.40	3.00
Total cost per annum	$573.56	$1,037.20	$1,532.00	$2,572.00
Cost of 1 h.p. per annum, 10-hr. basis	286.78	172.86	153.20	128.60
Cost of 1 h.p. per hr.	$0.0928	$0.0558	$0.0497	$0.0417

COST OF GAS POWER

$1.50 per 1,000 cu. ft. of gas less 20% if paid in 10 days = $1.20 net, gas 760 B.t.u.

Size of plant in h.p.	2	6	10	20
Engine cost if in place	$200.00	$375.00	$550.00	$1,050.00
Gas per h.p.-hr. in ft.	30	25	22	20
Value of gas consumed, 3,080 hrs.	$221.76	$554.40	$843.12	$1,478.00
Attendance, $1 per day	308.00	308.00	308.00	308.00
Interest, 5%	10.00	18.75	27.50	52.50
Depreciation, 5%	10.00	18.75	27.50	52.50
Repairs, 10%	20.00	37.50	55.00	105.00
Supplies, 20%	40.00	75.00	110.00	210.00
Insurance, 2%	4.00	7.50	11.00	21.00
Taxes, 1%	2.00	3.75	5.50	10.50
Power cost	$615.76	$1,023.65	$1,387.62	$2,237.50
Annual charge for space	9.00	13.50	18.00	27.00
Total cost per annum	$624.76	$1,037.15	$1,405.62	$2,264.50
Cost of 1 h.p. per annum, 10-hr. basis	312.38	172.86	140.56	113.22
Cost of 1 h.p. per hr.	$0.1014	$0.0561	$0.0456	$0.0367

COST OF STEAM POWER

Size of plant, h.p.	6	10	20
Cost of plant per h.p.	$250.00	$220.00	$200.00
Fixed charge, 14%	$35.00	$30.80	$28.00
Coal per h.p.-hr., in lbs.	20	15	12
Cost of coal at $5 per ton	$154.00	$103.00	$82.50
Attendance, 3,080 hrs.	75.00	50.00	30.00
Oil, waste and supplies	15.00	10.00	6.00
Cost 1 h.p. per ann., 10-hr. basis =	$279.00	$194.80	$146.50
Cost of 1 h.p. per hr.	$0.0906	$0.0832	$0.0475

ANNUAL COST OF POWER PER BRAKE-HORSE-POWER

B.h.p. of unit	Steam	Electricity	Gas	Gasoline
1	$600.00	$312.50	$380.00	$487.50
2	500.00	282.00	312.50	416.00
3	437.50	252.00	260.00	350.00
4	375.00	227.50	220.00	300.00
5	320.00	207.50	192.50	262.50
6	280.00	192.00	172.50	240.00
7	250.00	179.00	160.00	210.00
8	230.00	168.00	152.50	182.50
9	210.00	158.00	145.00	165.00
10	195.00	152.00	140.00	152.00
12	175.00	140.00	132.50	137.50
14	165.00	133.00	126.00	122.00
16	157.50	128.00	120.00	112.50
18	150.00	126.00	116.50	107.50
20	146.00	123.00	113.00	102.00
22	140.00	121.50	110.00	98.00
24	137.50	119.50	107.50	95.00
26	133.00	117.50	105.00	92.50
28	130.00	116.50	102.50	90.00
30	127.50	115.00	102.00	87.50
35	124.00	113.50	100.00	85.00
40	120.00	112.00	98.00	82.50
50	112.50	110.00	96.00	80.00
60	105.00	108.00	94.00	78.00
70	100.00	106.00	92.00	76.00
80	95.00	104.00	90.00	74.00
90	90.50	102.00	88.00	72.00
100	86.40	100.00	86.00	70.00

Unit costs = Coal, $5 per ton; electricity, $0.135 per kw.-hour; gas, $1.20 per 1,000 ft., at 760 B.t.u.; gasoline, $0.20 per gal.

The curves in Fig. 61 are averages for the 4 different kinds of power reported for the figures given in the table accompanying this paper.

Comparative Fuel Costs for Steam, Gasoline and Gas Engines. Table LVIII was published by the Otto Gas Engine Works, Philadelphia, Pa.

The Cost of Power. The following is abstracted from a paper by H. G. Stott, presented at a meeting of the Toronto Section of the A. I. E. E., Dec. 18, 1908.

In engineering estimates there is probably no item which contains so many variables as that representing the cost of power. Consequently we frequently find a wide divergence of opinion as to the results which may be expected under different conditions. In all types of plants the influence of investment upon the cost of power is one which is apt to be slighted in the estimates, and if not slighted it seems to be subject to more errors than any other factor which enters into this cost. This is particularly the case with hydraulic plants, as of necessity water storage, flumes, racks, tailrace, etc., enter into the estimate, with the result that the actual cost has sometimes been found to be 100% greater than the estimated cost.

In the same way indeterminate items of cost, such as foundations, cost of labor, etc., enter into practically all the calculations, so that

when we take into consideration the influence of location upon the cost of coal, labor and water, as well as upon the investment, it is readily seen that the actual cost of power is of necessity so variable as to make impossible anything like a standard cost per kw.-hr.

With the above limitations in mind, the following notes on the cost of power have been compiled with the idea that they might form a guide to show at least the fundamental relations between

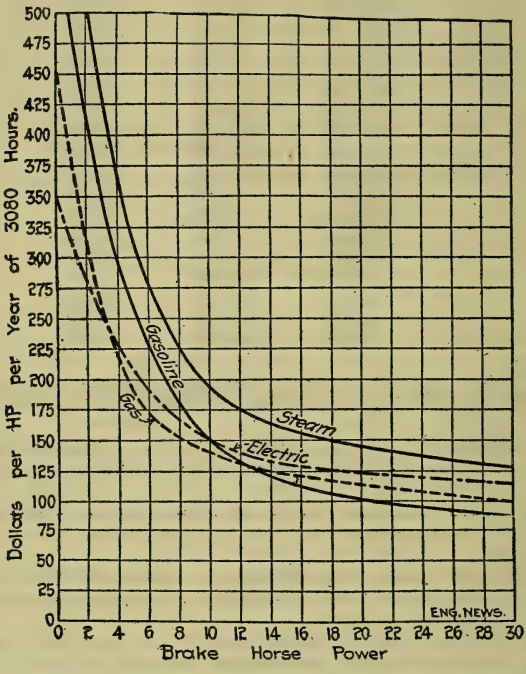


Fig. 61. Diagram showing comparative costs per brake horsepower of steam, electricity, gas and gasoline in small powers.

the various items going to make up the cost of power, and at the same time show what is actually being done to-day in large plants having a maximum load of over 30,000 kws.

Table LIX, taken from a paper contributed to the A. I. E. E. in 1906, has been expanded and revised so as to bring it up to the results obtained in practice in 1909. The principal changes made have been due to the better economy obtained in the steam turbine, and in the reduction of the total fixed charges from 12% to 11%; fixed charges composed of 5% interest, 1% taxes and

TABLE LVIII. COMPARATIVE COST OF FUEL

BASED ON FULL LOAD 10 HRS. PER DAY, 300 DAYS PER YR.

Type of engine	Fuel	Cost of fuel	Fuel consumption per brake hp. per hour: 50 hp.	100 hp.	200 hp.	300 hp.
Ordinary non-condensing steam engine	Bituminous coal	$3.00 per ton	8 lb.	6 lb.	5.5 lb.	......
Compound non-condensing steam engine	Bituminous coal	$3.00 per ton	......	......	5 lb.	4.5 lb.
Compound condensing steam engine or turbine	Bituminous coal	$3.00 per ton	......	......	4.5 lb.	4 lb.
Gasoline engine	Gasoline	10c. per gal.	.11 gal.	.11 gal.	......	......
Gas engine	Illuminating gas	$1.00 per 1000 ft.	16 cu. ft.	......	......	......
Gas engine	Natural gas	25c. per 1000 ft.	11 cu. ft.	10.5 ft.	10 ft.	10 ft.
Producer gas engine	Charcoal	$8.00 per ton	1.25 lb.	1.25 lb.	1.25 lb.	1.25 lb.
Producer gas engine	Coke	$5.00 per ton	1.75 lb.	1.75 lb.	1.75 lb.	1.75 lb.
Producer gas engine	Anthracite coal	$4.00 per ton	1.25 lb.	1.25 lb.	1.25 lb.	1.25 lb.
Producer gas engine	Lignite	$2.00 per ton	2.0 lb.	2.0 lb.	2.0 lb.	2.0 lb.

Type of engine	Fuel cost per year: 50 hp.	100 hp.	200 hp.	300 hp.	Total operating cost Incl. attendance, oil & supplies: 50 hp.	100 hp.	200 hp.	300 hp.
Ordinary non-condensing steam engine	$1608	$2512	$4422	....	$2400	$3450	$5700	....
Compound non-condensing steam engine	....	....	4020	$5427	....	....	5300	$7150
Compound condensing steam engine or turbine	....	....	3618	4824	....	....	4900	6550
Gasoline engine	1650	3300	....	....	1830	3470	....	....
Gas engine	2400	....	....	....	2500	....	....	....
Gas engine	412	784	1500	2250	512	950	2100	2900
Producer gas engine	670	1340	2680	4020	1045	1770	3140	4500
Producer gas engine	585	1170	2340	3510	960	1600	2800	4000
Producer gas engine	335	670	1340	2010	710	1100	1800	2500
Producer gas engine	267	534	1068	1602	642	964	1530	2100

general administrative expenses, and 5% for amortization or obsolescence in the steam and hydraulic plants.

TABLE LIX. RELATIVE COSTS PER KW.-HR. DISTRIBUTION OF MAINTENANCE AND OPERATION

Maintenance:	Reciprocating steam plant	Steam turbine plant	Reciprocating engines and low-pressure steam turbines	Gas-engine plant	Gas engines and steam turbines	Hydraulic
Engine room, mechanical..	2.59	0.51	1.55	5.18	2.84	0.51
Boiler or producer room..	4.65	4.33	3.55	1.16	1.97	...
Coal and ash-handling apparatus	0.58	0.54	0.44	0.29	0.29	...
Electrical apparatus	1.13	1.13	1.13	1.13	1.13	1.13
Operation:						
Coal	61.70	55.53	52.44	26.52	25.97	...
Water	7.20	0.65	0.61	3.60	2.16	...
Engine room, labor	6.75	1.36	4.06	6.76	4.06	1.36
Boiler or producer room labor	7.20	6.74	5.50	1.81	3.05	...
Coal and ash-handling labor	2.28	2.13	1.75	1.14	1.14	...
Ash removal	1.07	0.95	0.81	0.54	0.54	...
Electrical labor	2.54	2.54	2.54	2.54	2.54	2.54
Engine room lubrication...	1.78	0.35	1.02	1.80	1.07	0.20
Engine room waste, etc.....	0.30	0.30	0.30	0.30	0.30	0.20
Boiler room lubrication, etc.	0.17	0.17	0.17	0.17	0.17	...
Relative operating cost,%..	100.00	77.23	75.87	52.94	47.23	5.94
Relative investment, %.....	100.00	75.00	80.00	110.00	96.20	100.00
Probable average cost per kw.	125.00	93.75	100.00	137.50	120.00	125.00
Probable fixed charges, %..	11	11	11	12	11.5	11

For steam-turbine plants larger than 60,000 kw. the cost per kw. may be reduced to $75.

In the other items will be found changes due to the reduced cost of steam turbines, and also due to the possibility of saving the water of condensation by separating out the oil between the reciprocating engine and the steam turbine. Under the heading of *Coal,* in the reciprocating engine and steam turbine plant, it will be found that this amount has been increased so as to cover the difference between the theoretical amount which had to be assumed in 1906, and the actual amount guaranteed by the manufacturer in 1909.

In Figs. 62–83 the cost of delivered coal has been assumed at $3.00 per ton for a high grade coal having 14,500 B.t.u. per lb. and also at $1.50 per ton for a low-grade coal having 11,000 B.t.u. per lb. so as to illustrate the effect upon the cost of power.

Figs. 62 to 67 inclusive show with various types of plants, the fixed charges upon the upper curve and the operating charges below

the axis, so that the sum of the ordinates gives the total cost per kw.-hr. for any load factor on the plant. It will be noted that all the steam plants are assumed to have 50% overload capacity, sufficient to carry them over a peak-load of 2 hours, whilst the gas plant has no overload capacity. The combined gas-engine and steam-

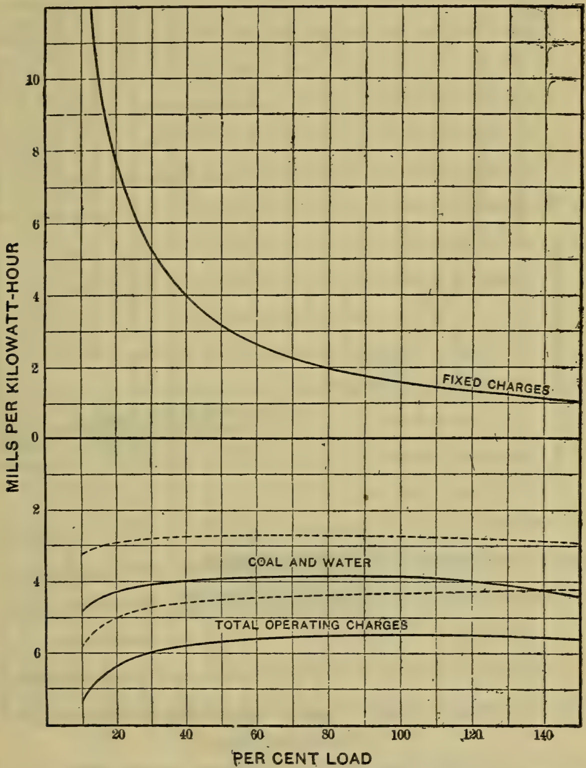


Fig. 62. Cost of power. Reciprocating steam-plant.
Plant cost = \$125 per kw.
Interest, taxes, depreciation, etc. = 11%.
Solid lines = coal at \$3.00 — 14,500 B.t.u. per lb.
Dotted lines = coal at \$1.50 — 11,000 B.t.u. per lb.

turbine plant has 25% and the hydraulic plant 10% overload capacity.

Figs. 68 to 75 inclusive show typical industrial, lighting (summer and winter), and railroad (summer and winter) load-curves. On

these Figs. will be found straight lines drawn through points corresponding to the necessary installed capacity of the various types of plants, and a second series of cost curves bringing out in a very suggestive manner the cost of furnishing power at every hour of

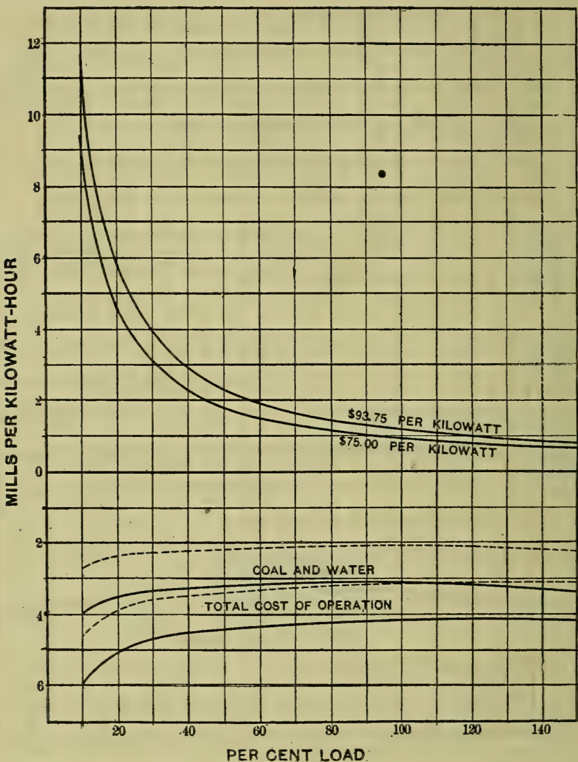


Fig. 63. Cost of power. Steam turbine plant.
Plant cost = $93.75 per kw.— A.
Plant cost = $75.00 per kw.— B.
Interest, taxes, depreciation, etc. = 11%.
Solid lines = coal at $3.00 — 14,500 B.t.u. per lb.
Dotted lines = coal at $1.50 — 11,000 B.t.u. per lb.

the day. As an illustration, refer to Fig. 72, which shows the cost of power on a summer lighting load.

During the greater part of the day, No. 4, or the gas-engine plant, is the most expensive, owing to the necessarily high fixed

charges. For the same reason, the reciprocating steam-engine plant is also high.

During the light morning load the hydraulic plant is also handi-

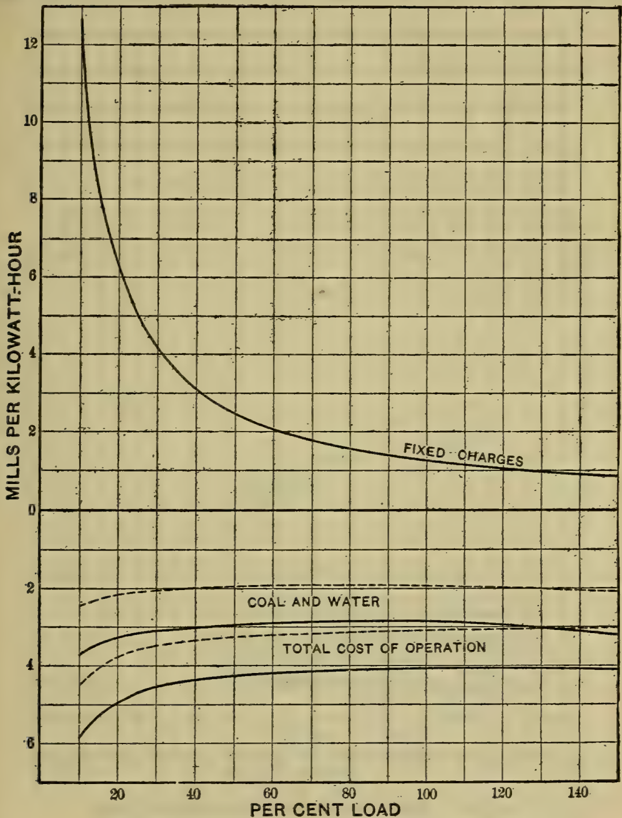


Fig. 64. Cost of power. Reciprocating engine and low-pressure turbine plant.

Plant cost = $100 per kw.
Interest, taxes, depreciation, etc. = 11%.
Solid lines = coal at $3.00 — 14,500 B.t.u. per lb.
Dotted lines = coal at $1.50 — 11,000 B.t.u. per lb.

capped by the fixed charges, but the low operating costs render it the more efficient upon the whole.

Fig. 66, representing the plant in which .5 the installed capacity

consists of gas engines and .5 of steam turbines, makes so excellent a showing on all the load-diagrams that we may expect to hear more of this type of plant in the future.

In all these comparisons it must be remembered that the costs

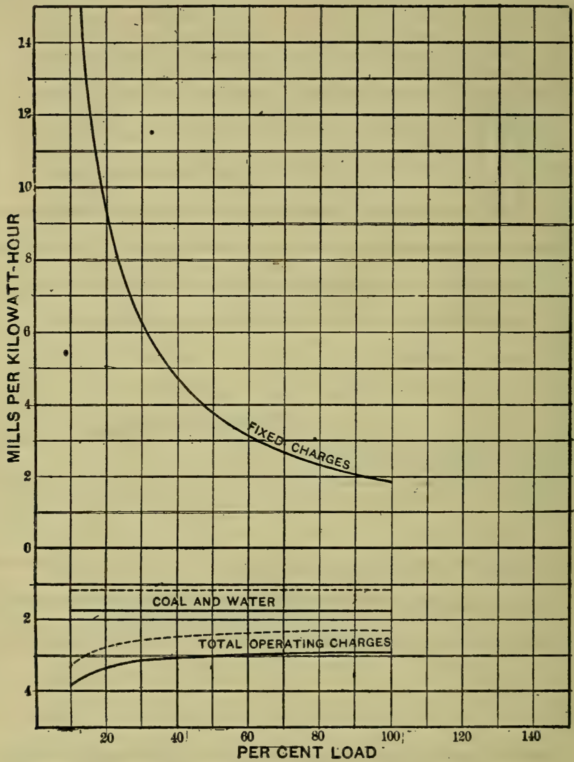


Fig. 65. Cost of power. Gas-engine plant.
Plant cost = $137.50 per kw.
Interest, taxes, depreciation, etc. = 12%.
Solid lines = coal at $3.00 — 14,500 B.t.u. per lb.
Dotted lines = coal at $1.50 — 11,000 B.t.u. per lb.

are worked out to the generating plant bus-bars only. In practically all cases, therefore, the costs discriminate in favor of the hydraulic plant, which almost invariably has to assume as a part of its expenses, the fixed charges and operating expenses of the transmission lines. Obviously, it was inadvisable to bring such an

unknown quantity into this comparison, but the fixed charges and operating expenses of a long-distance transmission line connecting to an hydraulic plant may be sufficient in many cases to decide

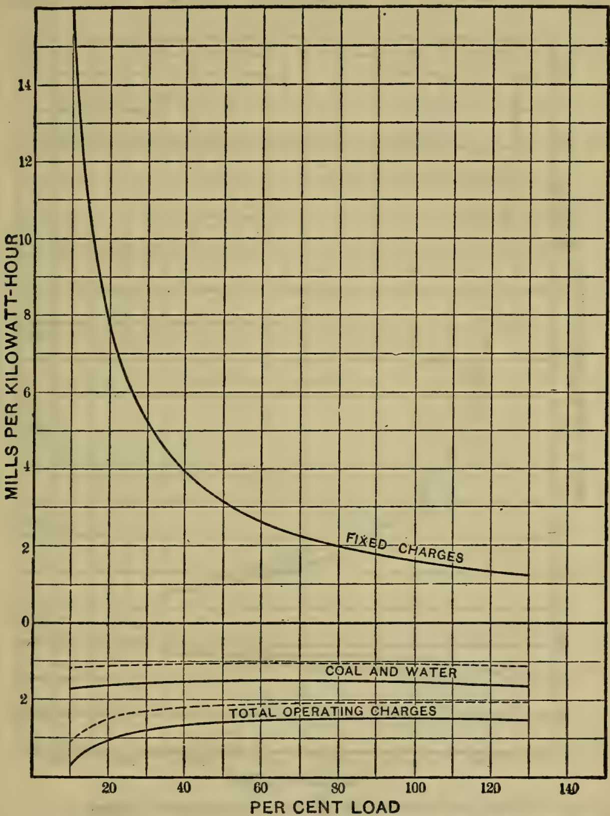


Fig. 66. Cost of power. Gas-engine and steam-turbine plant.
Plant cost = $120 per kw.
Interest, taxes, depreciation, etc. = 11.5%.
Solid lines = coal at $3.00 — 14,500 B.t.u. per lb.
Dotted lines = coal at $1.50 — 11,000 B.t.u. per lb.

the question of local steam or gas plant versus long-distance transmission from an hydraulic plant.

Figs. 76 to 81 are calculated from Figs. 62 to 67 and show the

power-plant costs per kw. per annum for various load-factors for each of the 6 types of plants. Attention is called to the fact that the result shown in Fig. 81 is for power at the bus-bars only, and that this must of necessity be increased by the fixed charges and maintenance costs of the transmission lines and transformers.

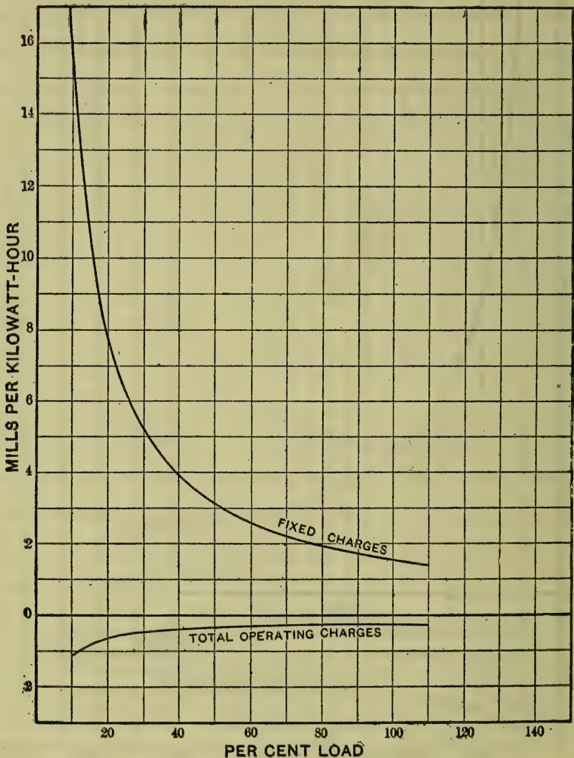


Fig. 67. Cost of power. Hydraulic plant.
Plant cost = $125 per kw.
Interest, taxes, depreciation, etc. = 11%.

Comparative Power Station Costs for Steam, Gas and Diesel Engines. The following is from a paper by Charles Day, in Power, Oct. 3, 1911. The great difficulty most buyers of power-plant machinery find is in securing reliable figures of power costs from people engaged in trade, except in the case of electric-supply

stations. The figures published in the Electrical Times cover practically almost all the supply stations in Great Britain, and this information combined with information obtained direct from station engineers has enabled the author to determine the average

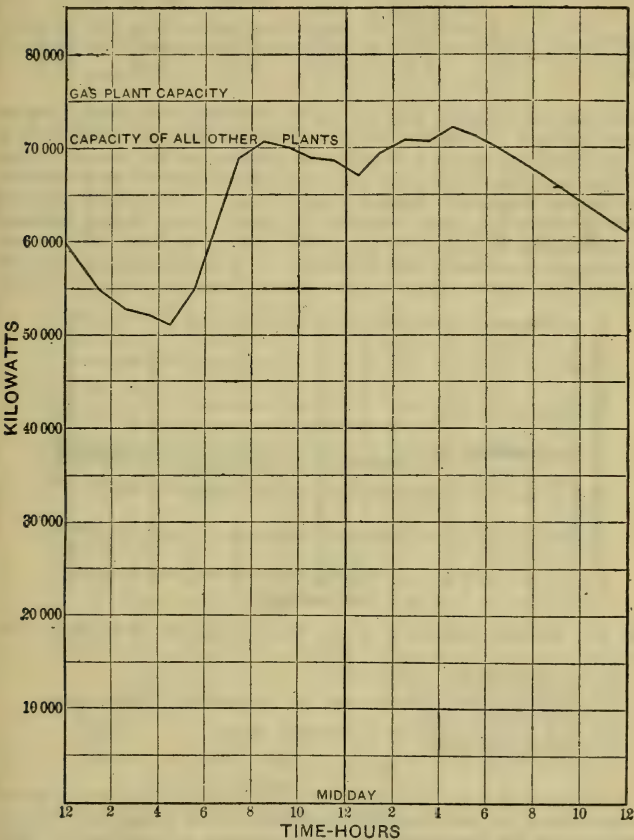


Fig. 68. Typical industrial load.

results obtained in such stations. With different types of plant these averages for stations having a plant capacity not exceeding 1000 horsepower, are as stated in Table LX.

The limit of 1000 h.p. was fixed owing to there being as yet no

TABLE LX. PENCE PER KW.-HR. SOLD

Type of engine	Fuel	Lubricating oil, waste, stores, and water	Wages	Repairs and maintenance	Total operating costs, pence	Load factor
Steam	0.45	0.06	0.25	0.26	1.02	14.7
Gas	0.43	0.09	0.28	0.24	1.04	15.3
Diesel	0.23	0.04	0.19	0.07	0.53	14.3

large electricity-supply stations equipped solely with Diesel engine or gas engines. Of course, better results are obtained when driving machinery which gives a better load factor, but the causes which produce loss are, as a rule, the same, though modified in extent. The general conclusion formed from a study of electricity stations holds good for the great majority of power users, though perhaps not applicable to some special trades, where engines can be run continuously on almost uniform loads. It is also necessary to point out that the figures include some items which should not strictly

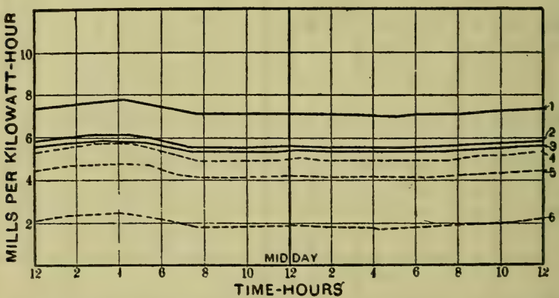


Fig. 69. Typical industrial load. Cost of power throughout the day.

1 = Reciprocating steam plant.
2 = Steam-turbine plant.
3 = Reciprocating engine and low pressure turbine plant.
4 = Gas-engine plant.
5 = Gas engine and steam-turbine plant.
6 = Hydraulic plant.

be charged against the power plant. For instance, the wages items include figures for men working on cables, street lamps, and in substations, and the repairs items include repairs to such parts. Also it is necessary to mention that the figures give the costs per unit of energy sold, not per unit generated.

From the averages it is clear that a substantial gain is obtained by the adoption of Diesel engines as against either gas or steam engines, the figures being beyond doubt substantially accurate. It is also noticeable that the gain is not only on fuel consumption,

but is practically in the same proportion on the other items of expenditure.

The great saving shown by these average figures is confirmed by repeated experiences of the author. In many cases, although the figures guaranteed with Diesel engines have been no better than figures previously guaranteed and obtained on tests, with existing steam and gas engines, the Diesel engines have shown over

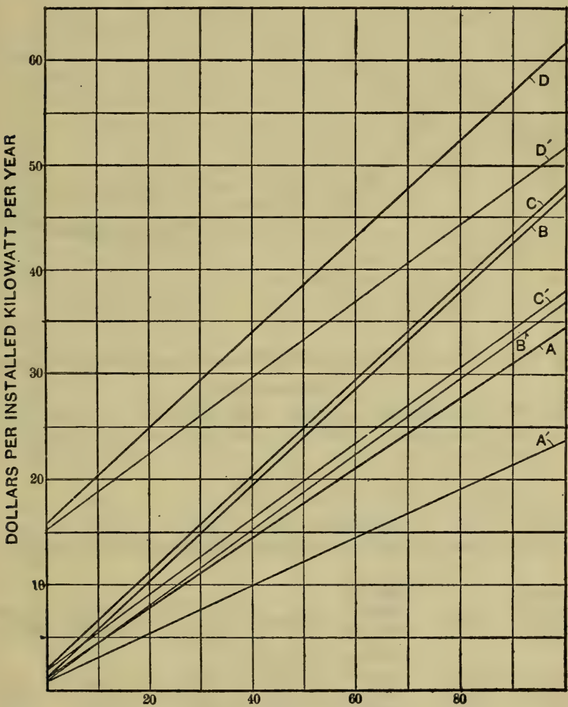


Fig. 70. Typical lighting load.

extended periods a saving of 50 and 60%, and in some cases an even greater percentage, the result being due to the fact that the Diesel engine's average working results were very much nearer to the guaranteed figures than with gas or steam engines, combined with the fact that the relatively high cost of working at light loads with gas or steam had not been sufficiently taken into account when considering the guaranteed figures.

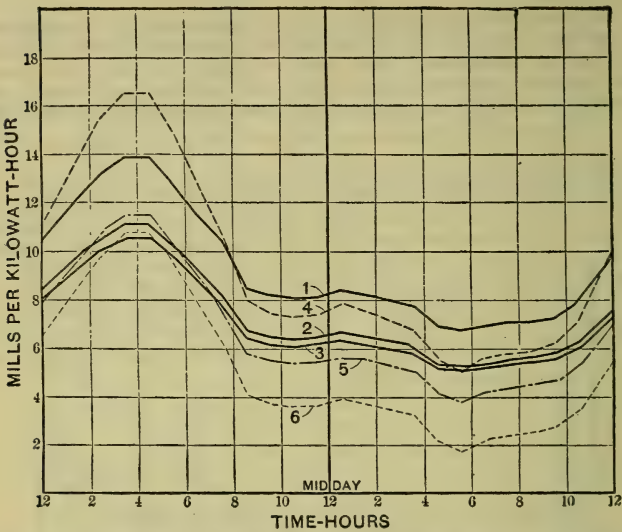


Fig. 71. Typical winter lighting load. Cost of power throughout the day. Curves 1, 2, 3, 4, 5 and 6 same as in Fig. 69.

TABLE LXI OPERATING COST, PENCE PER KW-HR. SOLD, FOR STEAM STATIONS OF DIFFERENT SIZES

Station capacity not exceeding, kw.	Fuel	Lubricating oil, waste, water and stores	Wages	Repairs and maintenance	Total, pence	Load factor
250	0.63	0.09	0.35	0.36	1.43	13.2
500	0.56	0.06	0.27	0.29	1.18	13.3
750	0.43	0.05	0.23	0.24	0.95	15.4
1,000	0.40	0.05	0.23	0.21	0.89	16.8
1,500	0.42	0.04	0.17	0.18	0.81	16.9
2,000	0.37	0.04	0.16	0.21	0.78	17.7
3,000	0.33	0.04	0.15	0.17	0.69	17.4
4,000	0.40	0.03	0.14	0.20	0.77	18.8
5,000	0.34	0.03	0.11	0.16	0.64	18.7
7,000	0.36	0.04	0.13	0.20	0.73	17.9
10,000	0.26	0.03	0.09	0.13	0.51	22.6
20,000	0.30	0.03	0.11	0.16	0.60	19.6
50,000	0.23	0.02	0.10	0.11	0.46	20.56

When going through cost records to prepare the average figures previously given, the author noticed very wide differences of cost per unit, particularly in the case of the steam plant. He therefore had the average cost calculated for steam stations of different capacity, and as the results are interesting, they are given separately in Table LXI.

It is to be noted that, even with the largest steam stations, the

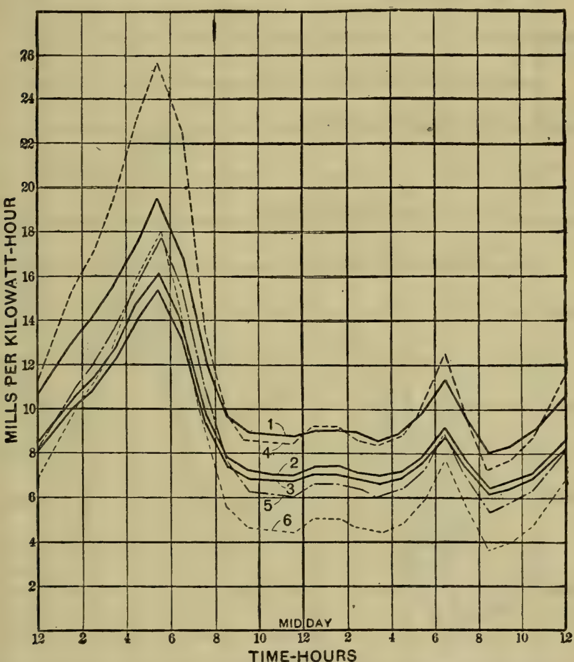


Fig. 72. Typical summer lighting load. Cost of power throughout the day. Curves 1, 2, 3, 4, 5 and 6 same as Fig. 69.

costs per unit generated are no better than for quite small stations using Diesel engines, and this in face of the improved load factor. This is a most important point, and shows that small Diesel stations can profitably supply current at prices hitherto thought to be obtainable only in densely populated centers having large power stations.

In all cases the figures which have been given are operating costs and do not include anything for interest on capital or depreciation. It is hardly possible to give a definite statement show-

ing the cost of constructing and equipping power houses of different types, as there are so many variable factors. However, the author's experiences of a considerable number of estimates indicates that up to a capacity of, say, 1000 kws. there is generally little difference between the gross capital expenditure required, whether steam, gas, or Diesel engines be adopted.

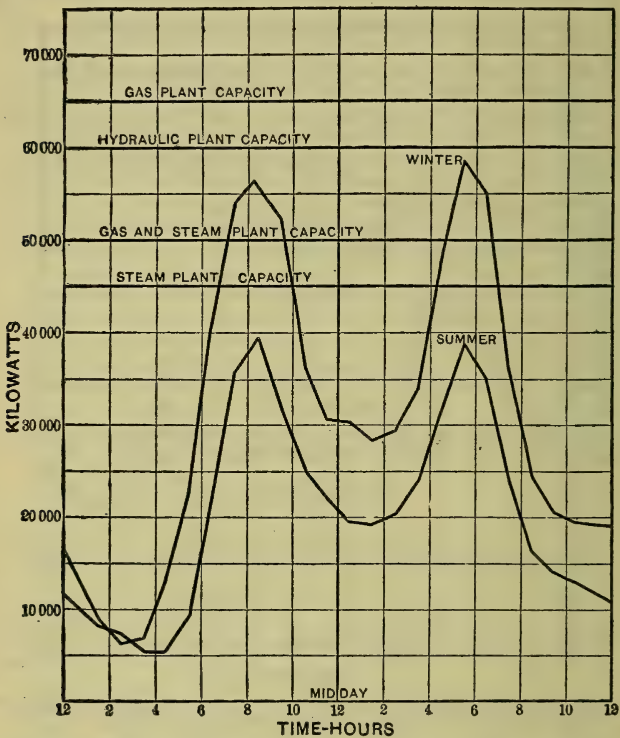


Fig. 73. Typical railway load.

The heat efficiency of the Diesel engine, though far from perfect, is still much better than any other heat engine, as is readily seen from the fuel consumption, which is 0.44 pound of fuel oil per brake horsepower per hour. The fuel consumption is also low at partial loads; being 0.45 pound at three-quarters load, 0.47 pound at half load and 0.62 pound at quarter load.

These are not "records" but everyday figures, and for engines

of moderate size. With larger engines the fuel consumption is rather lower, but increase of size does not give anything like the improvement in fuel consumption that occurs with steam engines.

Owing to the high economy at light loads it is often found distinctly advantageous to run a Diesel engine in preference to using a storage battery.

The oil generally used is residual petroleum; that is, the re-

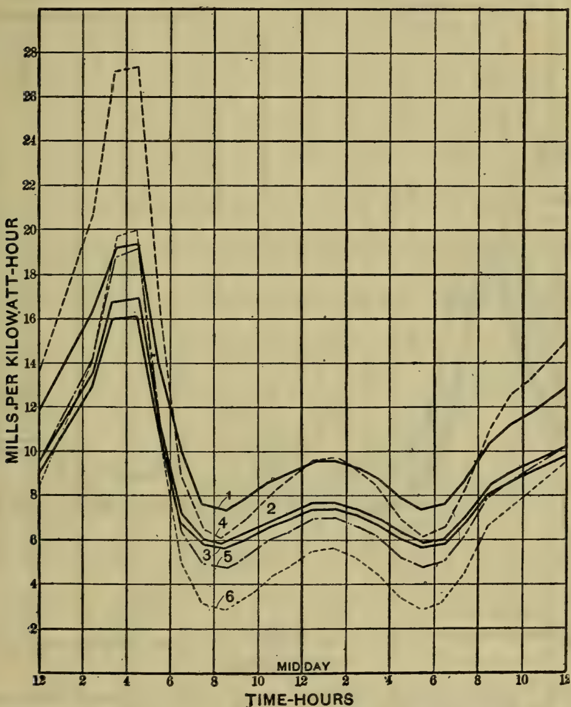


Fig. 74. Typical summer load. Cost of power throughout the day. Curves 1, 2, 3, 4, 5 and 6 same as in Fig. 69.

siduum left from petroleum after the lighter oils have been distilled off. The increased demand for gasolene will certainly tend to increase the further supply of residuum, while the opening up of new oilwells in various parts of the world is steadily increasing the oil supply.

The fuel oil used can be almost any of the fuel oils which are used for boiler firing, and a wide variety of oils can be used with no alteration of the engine, this being probably explained by the

fact that an atomizer which will sufficiently atomize a thick viscous oil can easily atomize the thinner oils. The use of oil fuel carries with it obvious advantages in the way of ease of handling and of cleanliness.

The question may naturally be asked whether Diesel engines are suitable for long periods of continuous running. In reply to this the following instance may be quoted:

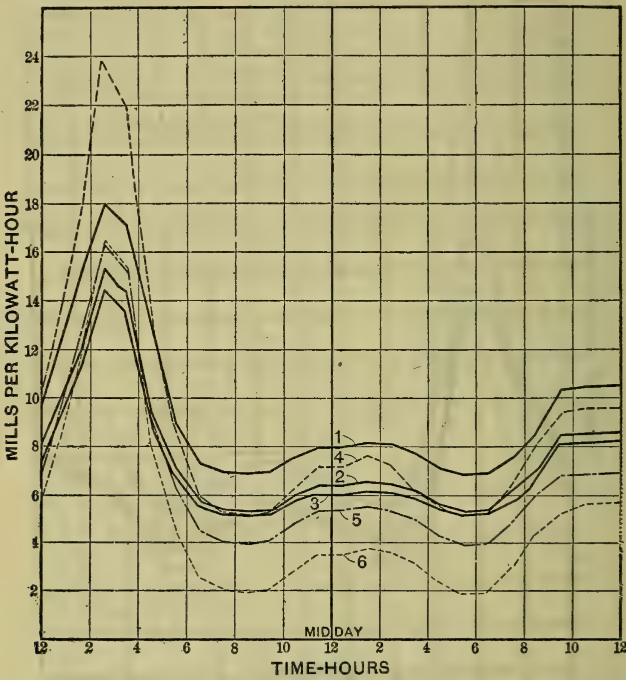


Fig. 75. Typical winter railway load. Cost of power throughout the day. Curves 1, 2, 3, 4, 5 and 6 same as in Fig. 69.

At the Birkdale Electricity Works a Mirrlees-Diesel was installed a little over four years ago. The station engineer recently made a report which showed that the engine had, on the average, worked 23.75 hours out of every 24 hours throughout the four years, or an average stoppage of about 1.75 hours each Sunday.

Average Costs of Installing and Operating Coal-Burning Steam Power Plants. Reginald Trautschold gives the following in Lefax.

The differentiated costs which together ordinarily make up the total cost of a steam power plant are:

Land for engine and boiler rooms	Accessories
Engine and boiler room building	Foundations
Chimneys	Piping
Boilers	Installation
Feed pumps, boiler	Freight and cartage
Engines	

$$\text{Cost of plant per brake h.p.} = \frac{\text{brake h.p. capacity of plant}}{\text{total cost of plant}} = \text{Item A.}$$

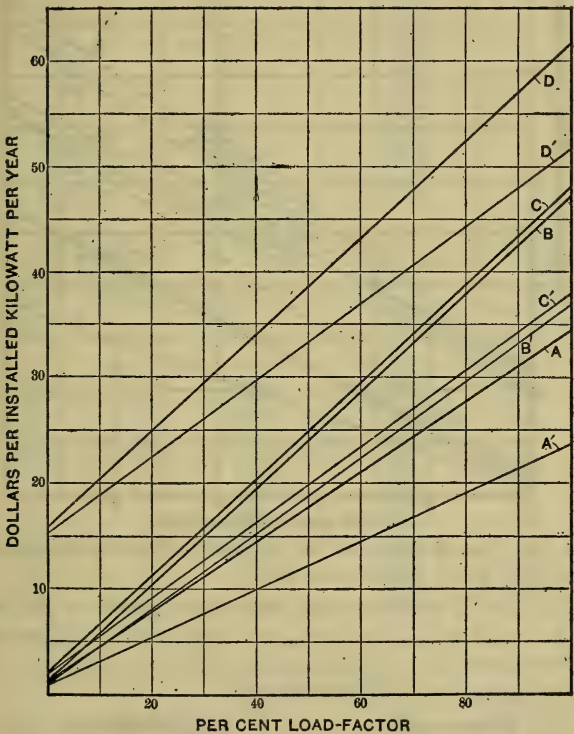


Fig. 76. Cost of power per kw. per year. Reciprocating steam-plant.

Plant cost \$125 per kw.
Fixed charges = 11%.
A, B, C, D = coal at \$3.00 — 14,500 B.t.u. per lb.
A′, B′, C′, D′, = coal at \$1.50 — 11,000 B.t.u. per lb.
A = Coal and water.
B = A + Mechanical maintenance and operation.
C = B + Electrical maintenance and operation.
D = C + Fixed charges.

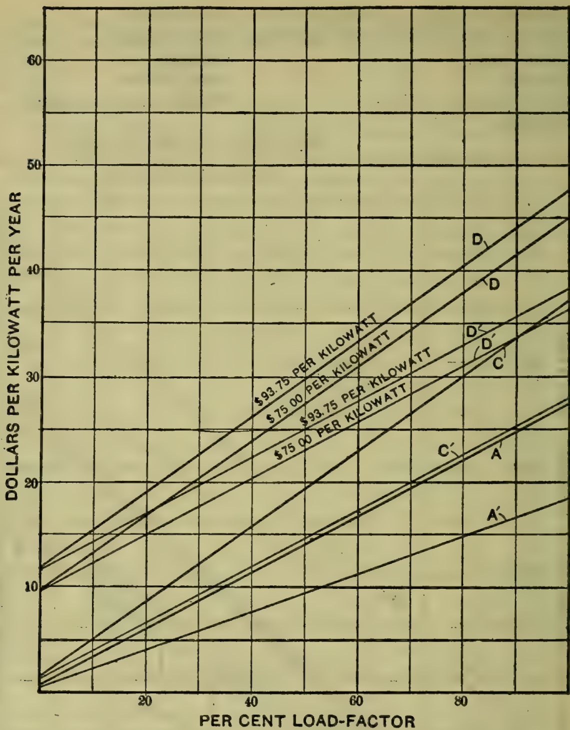


Fig. 77. Cost of power per kw. per year. Steam-turbine plant.

Plant cost $93.75 and $75 per kw.
Fixed charges, 11%.
A, B, C, and D same as in Fig. 76 = coal at $3.00 — 14,000 B.t.u. per lb.
A′, B′, C′ and D′ same as in Fig. 76 = coal at $1.50 — 11,000 B.t.u. per lb.

Fixed charges per year (yearly burden):

Depreciation	5 %	of total cost.
Repairs	2 %	" " "
Interest	6 %	" " "
Insurance	1 %	" " "
Taxes, 2% or .75 cost =	1.5%	" " "
Total	15.5%	" " "

Fixed charges per brake h.p.-yr. = 15.5% of Item A.

TABLE LXII

A. COST OF PLANT PER BRAKE H.P.

Size h.p.	Cost
100	$172
200	146
300	126
400	110
500	96
600	84
700	76
800	68
900	64
1000	60
1500	58
2000	56.50
2500	55
3000	54
4000	52
5000	50

B. FIXED CHARGES PER BRAKE H.P. YEAR, TAKEN AS 15.5% OF COST PER BRAKE H.P.

Size h.p.	Cost
100	$ 26.66
200	22.63
300	19.53
400	17.05
500	14.88
600	13.02
700	11.78
800	10.54
900	9.92
1000	9.30
1500	8.99
2000	8.76
2500	8.53
3000	8.37
4000	8.06
5000	7.75

C. COST OF ATTENDANCE PER BRAKE H.P. YEAR (308 DAYS)

Size of plant h.p.	Operative hours per day 10	24
100	$12.00	$24.00
200	10.00	20.00
300	8.60	17.20
400	7.25	14.50
500	6.20	12.40
600	5.40	10.80
700	4.70	9.40
800	4.15	8.30
900	3.75	7.50
1000	3.50	7.00
1500	3.25	6.50
2000	3.15	6.30
2500	3.05	6.10
3000	2.75	5.50
4000	2.50	5.00
5000	2.25	4.50

D. COST OF OIL, WASTE AND SUPPLIES PER BRAKE H.P. YEAR (308 DAYS)

Size of plant h.p.	Operative hours per day 10	24
100	$ 2.40	$ 5.76
200	2.00	4.80
300	1.72	4.13
400	1.45	3.48
500	1.24	2.88
600	1.08	2.60
700	.94	2.26
800	.83	1.99
900	.75	1.80
1000	.70	1.68
1500	.65	1.56
2000	.60	1.44
2500	.55	1.32
3000	.50	1.20
4000	.40	.96
5000	.35	.84

TABLE LXIII. COAL CONSUMPTION PER BRAKE H.P. YEAR (308 DAYS)

Size of plant h.p.	Operative hours per day 10	24	Size of plant h.p.	Operative hours per day 10	24
100	10.00 tons	20.00 tons	900	4.15 tons	8.30 tons
200	9.00	18.00	1000	3.45	6.90
300	8.25	16.50	1500	2.80	5.60
400	8.00	16.00	2000	2.40	4.80
500	7.10	14.20	2500	2.10	4.20
600	6.20	12.40	3000	1.85	3.70
700	5.50	11.00	4000	1.72	3.44
800	4.80	9.60	5000	1.55	3.10

TABLE LXIV. TOTAL COST OF POWER PER BRAKE H.P. YEAR (308 DAYS)

Size plant h.p.	Cost of coal per ton $2.00 Service 10 hr.	24 hr.	$3.00 Service 10 hr.	24 hr.	$4.00 Service 10 hr.	24 hr.	$5.00 Service 10 hr.	24 hr.
100	$61.06	$96.42	$71.06	$116.42	$81.06	$136.42	$91.06	$156.42
200	52.63	83.43	61.63	101.43	70.63	119.43	79.63	137.43
300	46.35	73.86	54.60	90.36	62.85	106.86	71.10	123.36
400	41.75	67.03	49.75	83.03	57.75	99.03	65.75	115.03
500	36.52	58.56	43.62	72.76	50.72	86.98	57.82	101.16
600	31.90	51.22	38.10	63.62	44.30	76.02	50.50	88.42
700	28.42	45.44	33.92	56.44	39.42	67.44	44.92	78.44
800	25.22	40.03	30.02	49.63	34.82	59.23	39.62	68.83
900	22.72	35.82	26.87	44.12	31.02	52.43	35.17	60.72
1000	20.40	31.78	23.85	38.68	27.30	45.58	30.75	52.48
1500	18.49	28.25	21.29	33.85	24.09	39.45	26.89	45.05
2000	17.31	26.10	19.71	30.90	22.11	35.70	24.51	40.50
2500	16.33	24.35	18.43	28.55	20.53	32.75	22.63	36.95
3000	15.32	22.47	17.17	26.17	19.02	29.87	20.87	33.57
4000	14.40	20.90	16.12	24.34	17.84	27.78	19.56	31.22
5000	13.45	19.29	15.00	22.39	16.55	25.49	18.10	28.59

Cost of power is at engine; no transmission or conversion losses considered.

EXAMPLE

2500-brake h.p. plant, operated 10 hrs. per day, 308 days per yr., coal $4.00 per ton.

Cost of plant (Table LXII-A)	$137,500
Yearly fixed charges (Table LXII-B)	$ 21,325
Yearly cost of attendance (Table LXII-C)	7,625
Yearly cost of supplies (Table LXII-D)	1,375
Yearly coal, 5,250 tons (Table LXIII)	21,000
Total cost of power per year (Table LXIV)	$ 51,325

Total cost of power per brake h.p.-hr. (Table LXV) $.00667 or ⅔ ct.

Steam Power Plant Costs. The following estimated costs were given in a report of the Hydro-Electric Power Commission of the Province of Ontario, reprinted in Engineering News, Dec. 1907.

CAPITAL COSTS OF STEAM POWER PLANTS AND ANNUAL COSTS OF POWER PER B.H.P.

Size of plant, h.p.	Capital cost of plant per h.p. installed: Engines boilers, etc., installed	Buildings	Total	Annual cost of 10-hr. power per b.h.p.	Annual cost of 24-hr. power per b.h.p.
Engines. Simple, slide valve, non-condensing. Boilers; Return tubular.					
10	$66.00	$40.00	$106.00	$91.16	$180.76
20	56.00	37.00	93.00	76.31	151.48
30	48.70	35.00	83.70	66.46	131.68
40	44.75	33.50	78.25	59.49	117.74
50	43.00	31.00	74.00	53.95	106.46

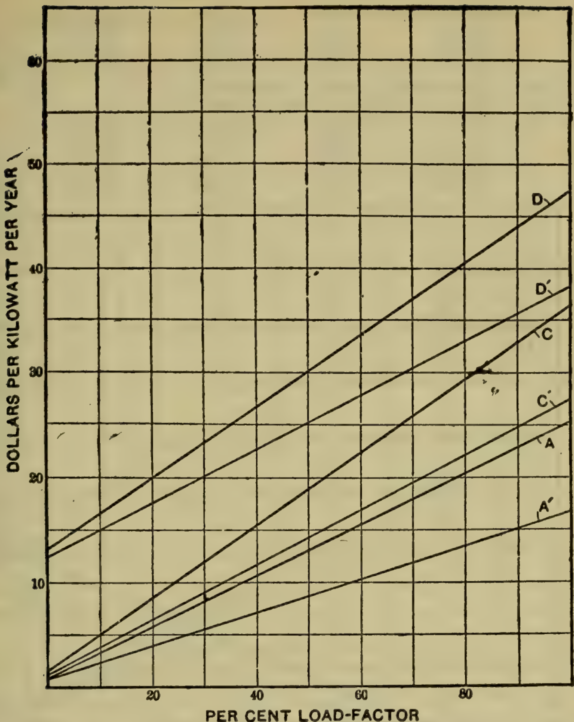


Fig. 78. Cost of power per kw. per year. Reciprocating-engine and low-pressure turbine plant.

Plant cost $100 per kw.
Fixed charges 11%.
A, B, C, D
A′, B′, C′, D′ } same as Fig. 76.

Engines: Simple, Corliss, non-condensing.
Boilers: Return tubular.

30	70.70	35.00	105.70	61.14	117.70
40	62.85	33.50	96.35	55.50	107.10
50	59.00	31.00	90.00	50.70	97.73
60	56.00	30.00	86.70	47.42	91.34
80	50.00	27.50	77.50	43.86	85.41
100	44.60	25.00	69.60	40.55	79.19

Engines: Compound, Corliss, condensing.
Boilers: Return tubular, with reserve capacity.

100	63.40	28.00	91.40	33.18	60.05
150	53.70	24.00	77.70	29.83	54.63
200	50.10	20.00	70.10	28.14	51.72
300	45.90	18.00	63.90	26.27	48.83

400	43.55	16.00	59.55	24.84	46.12
500	41.25	14.00	55.25	23.73	44.21
750	40.50	13.00	53.50	23.56	44.02
1,000	39.00	12.00	51.00	23.26	43.71

Engines: Compound, Corliss, condensing.
Boilers: Water-tube, with reserve capacity.

300	55.20	18.00	73.20	25.77	46.32
400	51.50	16.00	67.50	24.18	43.61
500	49.40	14.00	63.40	23.19	42.03
750	46.80	13.00	59.70	22.88	41.56
1,000	44.30	12.00	56.80	22.47	41.11

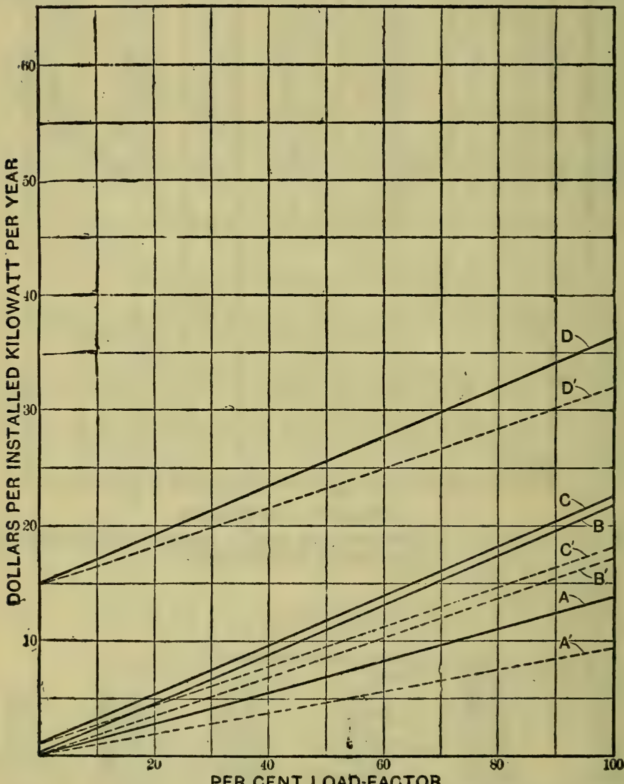


Fig. 79. Cost of power per kw. per year. Gas-engine plant.
Plant cost = $137.50 per kw.
Fixed charges 12%.
Solid lines, Dotted lines, A, B, C, D } same as Fig. 76.

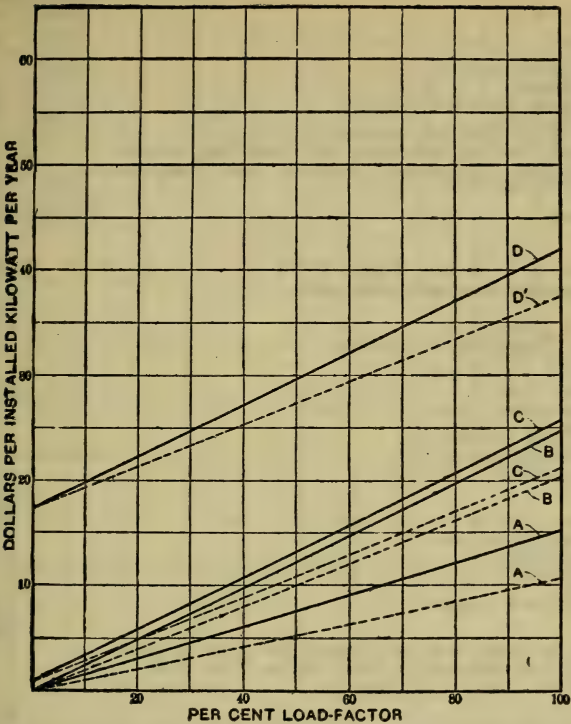


Fig. 80. Cost of power per kw. per year. Gas-engine and steam-turbine plant.

Plant cost = $120 per kw.
Fixed charges 11.5% per annum.
Solid lines, Dotted lines, A, B, C, D } same as in Fig. 76.

Boiler Room Equipment Costs Per Rated Boiler Horse-Power. The following, by O. S. Lyford, Jr., and R. W. Stovel for plants using coal for fuel, was taken from Electric Journal, April, 1912.

	Dols per h.p. High	Low
Boilers exclusive of masonry setting	$11.00	$ 8.00
Superheaters	3.00	0
Stokers	5.50	3.00
Masonry settings for boilers	3.50	2.00
Flues	1.50	0.75

	Dols. per h.p. High	Low
Stacks	4.00	2.00
Economizers	4.00	0
Mechanical Draft	3.00	0
Feed-Pumps	1.50	0.50
All Piping and Pipe Covering	10.00	6.00
Feed-Heaters	1.00	0.40
Coal Chutes and Ash Hoppers	1.25	0
Various, such as Indicating and Recording Devices, Damper Regulator, Ladders and Runways, Painting, etc	1.00	0.50
Totals	$50.25	$23.15

Cost of a 10 h.p. Steam Plant as given by W. O. Webber, Engineering Magazine, Feb., 1907.

10 h.p. boiler	$ 300
Boiler foundation and setting	160
Blow-off tank	31
Damper and regulator	75
Injector tank	10
Water meter	40
Piping for same	20
Pump and vacuum	122
Feed-water heater	40
Pipe covering	50
	$789
Engine, 7 by 10	$ 184
Foundation for same	60
Steam separator	35
Oil separator	25
Piping	95
Freight and cartage	30
	$429
Land for engine and boiler room, 300 sq. ft. at $1.00	$ 300
Boiler and engine-room bldg., 300 sq. ft. at $1.50	450
Chimney, 18-in. by 40-ft.	400
	$1,150
Total	$2,368

Note. These figures of Mr. Webber's evidently include labor in each item. His allowance of $1.00 per sq. ft. for land would be high in some places because it amounts to over $43,000 per acre.

Cost of a 60-h.p. Steam Plant. Mr. Webber is authority for the following, also.

Land for engine and boiler room	$ 2,500.00
Buildings for engine and boiler room	2,500.00
Chimney	1,200.00
80-h.p. boiler	790.00
Ash pan for boiler (below high-tide level)	120.00
Boiler and engine settings	1,282.00
Blow-off tank	31.00
Damper regulator	75.00
Injector tank	10.00
Water meter	60.00

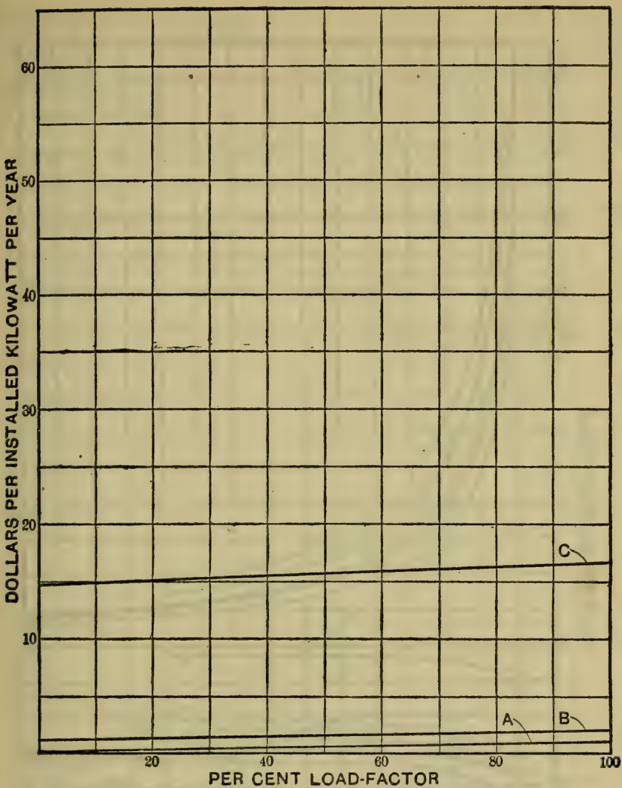


Fig. 81. Cost of power per kw. per year. Hydraulic plant.
Plant cost = \$125 per kw.
Fixed charges, 11% per annum.
A = Mechanical maintenance and operation.
B = A + Electrical maintenance and operation.
C = B + Fixed charges.

Piping for same	22.13
Pump and receiver	146.50
Feed-water heater	70.40
Pipe covering	70.75
	\$ 2,677.78
Engine, 12 by 30	\$ 1,065.00
Pan for engine fly wheel	72.00
Steam separator	60.00

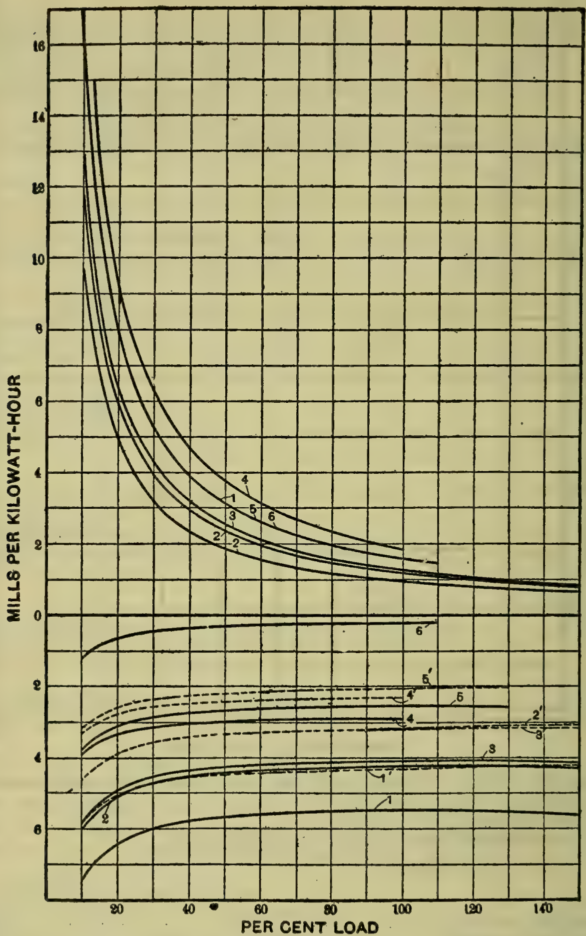


Fig. 82. Summary of Figs. 1 to 4 inclusive.
Curves 1, 2, 3, 4, 5, and 6 same as Fig. 69.

Oil separator	41.00
Piping, freight and cartage	1,026.41
	$ 2,265.21
Shafting in place	$ 550.00
Belting in place	285.00
	$ 835.00
Total	$11,977.99

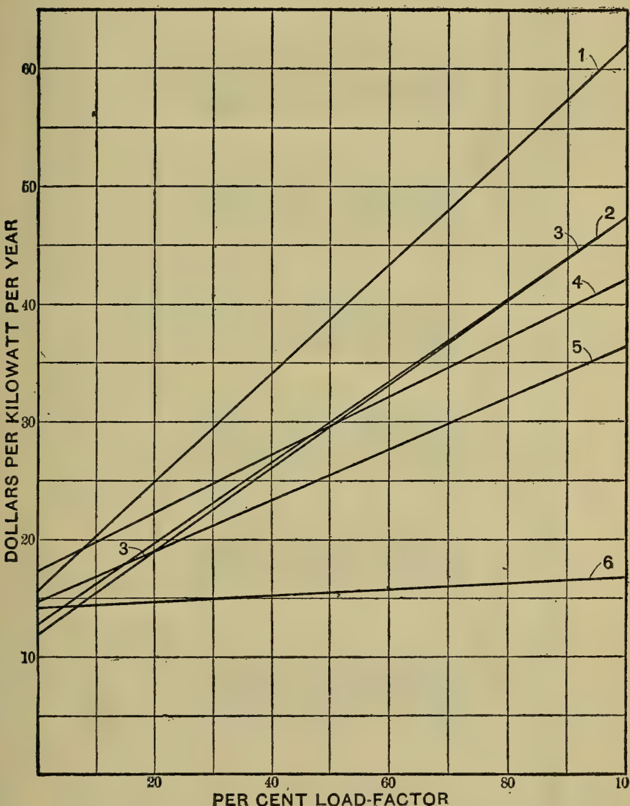


Fig. 83. Summary of Figs. 76 to 81 inclusive.
Curves 1, 2, 3, 4, 5, and 6 same as Fig. 69.
Coal at $3.00 — 14,500 B.t.u. per lb.

TABLE LXV. TOTAL COST OF POWER PER BRAKE H.P. HOUR (308 DAYS PER YEAR)

Size plant	Cost of coal per ton							
	Coal at $2.00 ton Service		Coal, $3.00 ton Service		Coal, $4.00 ton Service		Coal, $5.00 ton Service	
h.p.	10 hr.	24 hr.	10 hr.	24 hr.	10 hr.	24 hr.	10 hr.	24 hr.
100	$0.02000	$0.01333	$0.02355	$0.01575	$0.02628	$0.01843	$0.02954	$0.02115
200	0.01708	0.01128	0.02000	0.01371	0.02290	0.01618	0.02583	0.01859
300	0.01505	0.00999	0.01773	0.01221	0.02040	0.01445	0.02305	0.01669
400	0.01354	0.00908	0.01615	0.01127	0.01875	0.01340	0.02133	0.01554
500	0.01186	0.00793	0.01321	0.00982	0.01645	0.01176	0.01876	0.01370
600	0.01036	0.00694	0.01238	0.00860	0.01440	0.01029	0.01640	0.01196
700	0.00925	0.00615	0.01115	0.00763	0.01281	0.00911	0.01460	0.01060
800	0.00822	0.00546	0.00983	0.00671	0.01132	0.00801	0.01297	0.00932
900	0.00739	0.00486	0.00874	0.00596	0.01007	0.00709	0.01140	0.00821
1000	0.00666	0.00430	0.00776	0.00523	0.00888	0.00616	0.01000	0.00709
1500	0.00601	0.00383	0.00693	0.00458	0.00784	0.00533	0.00875	0.00609
2000	0.00563	0.00354	0.00641	0.00416	0.00719	0.00483	0.00797	0.00548
2500	0.00531	0.00330	0.00599	0.00386	0.00667	0.00443	0.00737	0.00500
3000	0.00499	0.00305	0.00558	0.00354	0.00619	0.00404	0.00679	0.00453
4000	0.00468	0.00283	0.00524	0.00329	0.00580	0.00376	0.00636	0.00422
5000	0.00437	0.00261	0.00488	0.00303	0.00538	0.00345	0.00588	0.00386

Cost of power is at engine; no transmission or conversion losses considered.

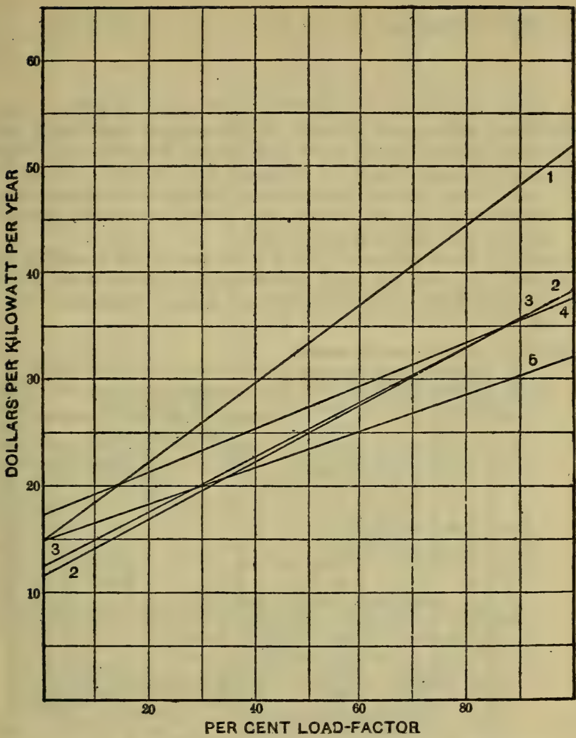


Fig. 84. Summary of Figs. 76 to 81 inclusive.
Curves 1, 2, 3, 4, 5, and 6 same as Fig. 69.
Coal at $1.50 — 11,000 B.t.u. per lb.

Note. These costs include labor and incidentals. The item for land is very high except in cities of the first or second class.

Average Cost of Compound Condensing Steam Plants. W. H. Weston has given the following, Engineering Magazine, January, 1912:

H.P.		Cost
100	Without Economizers	$ 10,000
200	" "	19,000
300	" "	25,500
400	" "	31,000
500	With "	28,000
600	" "	38,000
800	" "	56,500
1,000	" "	66,500

H.P.		Cost
1,500	With Economizers	95,000
2,000	" "	121,000
4,000	" "	225,000

The above figures do not include mechanical stokers or ash- or coal-handling equipments, but do include engine and boiler houses, engine foundations, condenser and pump foundations, chimney, boilers (including settings and fittings), economizers (except where noted), all piping, valves, feed pumps, heaters and separators; engines, condensers, air and circulating pumps, and also allowing $1 or $2 per h.p. for miscellaneous costs.

Mr. Weston says that for 1000 h.p. or more, ash-handling plants cost $0.50 to $3 per h.p., and coal-handling plants from $1 to $6 per h.p.; these being so dependent upon special conditions that they

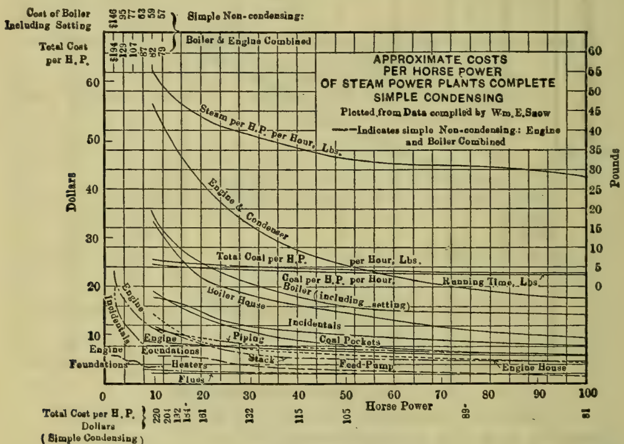


Fig. 85. Approximate cost per h.p. of steam power plants complete.

should be calculated for each plant independently, rather than trusting to average figures which vary very widely between these limits and even exceed them.

Approximate Cost Per h.p. of Steam Power Plants Complete. Simple Condensing. Fig. 85 was plotted from data compiled by Wm. E. Snow, as given in Tables LXVI–LXIX.

The Estimated Cost per h.p. of Steam Power Plant Complete. After Wm. E. Snow, Engineering Magazine, May, 1908. Tables LXVI–LXIX were compiled from a large amount of data, obtained in many small power stations at various places, and are believed to be sufficiently accurate for any purpose of ordinary estimating. They are naturally general averages or approximations thereto.

TABLE LXVI. SIMPLE NON-CONDENSING; BOILER AND ENGINE COMBINED

Horsepower of engine	2	3	4	6	8	10	12
Boiler, including setting	$146.00	$108.00	$ 95.00	$ 77.00	$63.00	$59.00	$57.00
Engine	22.80	19.40	17.00	14.80	12.60	11.40	10.30
Engine foundations	5.70	5.70	4.50	4.50	3.40	3.40	3.40
Incidentals	19.40	13.70	12.50	10.30	8.00	8.00	8.00
Total cost per h.p.	200.00	152.00	133.00	110.00	89.00	83.00	78.00

TABLE LXVII. BOILER AND ENGINE INDEPENDENT, SIMPLE NON-CONDENSING

H.p. of engine	10	12	14	15	20	30	40	50	75
Steam per h.p.-hr., lbs.	64.3	60.1	57.2	55.4	52.3	45.1	42.3	40.2	36.5
Coal per h.p. per hr., running time	...	...	...	...	...	...	...	...	...
Total coal per h.p. per hr.	...	...	...	...	...	...	...	...	...
Boiler, including setting	$ 56.00	$ 51.00	$ 46.00	$ 43.50	$ 32.00	$ 26.00	$ 24.00	$20.56	$17.30
Flues	2.30	2.30	2.30	2.30	2.25	2.20	2.15	2.10	2.00
Stack	16.00	14.80	13.40	13.00	11.60	8.70	7.30	6.30	5.60
Feed pumps	5.70	5.50	5.50	5.40	5.40	3.80	3.15	2.75	2.10
Engine	36.50	36.00	35.50	35.00	34.50	28.50	21.50	17.40	15.50
Engine foundations	5.70	5.50	5.40	5.35	5.25	5.15	5.05	4.90	4.60
Piping	8.30	8.00	7.60	7.40	6.70	5.70	5.10	4.60	3.90
Heaters	2.96	2.75	2.70	2.60	2.50	2.20	2.15	2.05	1.90
Boiler house	37.50	33.00	30.00	28.50	24.50	20.50	18.00	16.00	13.00
Engine house	4.80	4.35	4.00	3.90	3.30	2.75	2.50	2.30	2.15
Coal pocket	21.00	19.40	17.20	16.90	14.80	12.00	10.80	9.40	7.00
Incidentals	20.00	18.00	16.00	15.00	13.70	11.00	9.80	8.30	6.00
Total cost per h.p.	218.00	200.00	190.00	180.00	156.00	130.00	110.00	99.00	82.00

TABLE LXVIII. COMPOUND CONDENSING

H.p. of engine	100	200	300	400	500	600	700	800	900	1000	1500	2000
Steam per h.p. per hr., lbs.	24.1	22.3	20.2	19.5	19.0	18.1	17.3	16.2	15.1	14.5	13.9	13.5
Coal per h.p. per hr., running time	2.75	2.45	2.40	2.35	2.30	2.25	2.20	2.15	2.10	1.95	1.80	1.75
Total coal per h.p. per hr.	3.15	2.85	2.75	2.70	2.65	2.60	2.55	2.50	2.45	2.25	2.07	2.02
Boilers, including setting	$8.00	$7.60	$7.40	$7.30	$7.25	$7.20	$7.15	$7.05	$6.90	$6.80	$6.60	$6.40
Flues	1.93	1.82	1.59	1.36	1.12	1.02	0.92	0.80	0.68	0.57	0.57	0.57
Stack	4.55	4.00	3.65	3.30	3.08	2.95	2.90	2.85	2.80	2.75	2.70	2.68
Feed pumps	0.93	0.57	0.46	0.37	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.19
Engine and Condenser	25.00	24.00	23.00	22.00	21.50	21.25	21.	20.75	20.50	20.25	19.50	19.
Engine foundation	5.70	5.60	5.50	5.40	5.30	5.20	5.10	5.	4.90	4.80	4.40	4.10
Piping	13.80	11.20	9.10	8.00	7.40	6.80	6.50	6.25	6.	5.75	5.10	4.55
Heaters	2.85	2.55	2.25	2.00	1.75	1.42	1.12	1.12	1.	1.	0.95	0.95
Boiler house			11.20	8.00	6.40	5.70	5.35	5.	4.68	4.55	4.10	3.96
Engine house	28.50	24.00	11.20	9.35	8.50	7.20	6.20	5.60	5.35	5.	4.75	4.55
Coal pocket	5.70	4.00	3.10	2.60	2.40	2.27	2.16	2.05	1.93	1.82	1.73	1.61
Incidentals	9.70	8.00	6.80	6.50	6.25	6.	5.75	5.50	5.25	5.	4.75	4.60
Total cost per h.p.	106.60	93.30	86.20	76.20	71.20	67.30	64.40	62.20	59.30	55.70	54.40	53.20

TABLE LXIX. SIMPLE CONDENSING

Hp. of engine	10	12	14	15	20	30	40	50	75	100
Steam per hp. per hr., lb.	55.9	52.1	48.7	47.3	44.2	39.	36.2	33.	31.1	28.2
Coal per hp. per hr., running time, lb.	6.1	5.9	5.7	5.25	4.80	4.60	4.20	3.75	3.40	3.10
Total coal per hp. per hr., lbs.	7.0	6.75	6.50	6.02	5.50	5.25	4.75	4.25	3.70	3.50
Boiler, including setting	$35.50	$33.10	$29.60	$28.50	$25.10	$20.50	$17.80	$15.80	$14.80	$14.20
Flues	2.28	2.28	2.28	2.28	2.20	2.15	2.10	2.05	2.05	2.00
Stack	12.	10.70	9.70	9.40	8.50	6.30	5.70	5.25	4.80	4.55
Feed pumps	5.70	5.70	5.70	5.70	5.40	3.80	3.10	2.75	2.10	1.70
Engine and condenser	57.	54.	50.	48.	41.50	32.50	27.50	24.20	19.60	17.60
Engine foundations	8.50	8.38	8.30	8.10	7.80	7.40	7.	6.70	6.	5.70
Piping	11.20	11.	10.70	10.20	9.50	8.	7.70	7.30	6.10	5.70
Heaters	2.95	2.75	2.70	2.65	2.50	2.30	2.17	2.10	1.98	1.80
Boiler house	33.70	29.60	27.50	26.20	21.60	18.20	16.	14.80	11.30	9.70
Engine house	14.40	12.60	11.30	10.90	8.60	7.75	6.40	5.35	4.90	4.30
Coal pocket	19.	17.90	16.60	15.80	13.60	11.	8.70	8.50	6.30	5.70
Incidentals	18.	17.60	17.	16.60	14.70	11.80	10.90	10.30	8.70	7.80
Total cost per hp.	$220	$204.	$192.	$186.	$163.	$134.	$120.	$108.	$93.	$81.

Cost of a Steam Power Plant for a Textile Mill. F. B. Rhea, Southern Electrician, Feb., 1912, gives the following table for the cost of complete installation per h.p. of such a plant.

Engine and condenser	$13.67
Piping, etc.	3.70
Fire tube boilers	5.00
Fan and stack	1.82
Installing fire tube boilers	1.21
Foundation	1.26
Boiler pumps	0.25
Economizer	3.92
Drive	1.00
Piping in to boiler	0.90
Pipe covering	0.50
Total	$33.23

This is understood to represent a 2,500-h.p. plant with pump, hot-well and jet condenser and all piping between the condenser head and hot-well, the engine being delivered and erected on purchaser's foundation at competitive point in the Carolinas. The plant is figured to drive a 55,000 spindle cotton mill, the engines being 32 and 64 by 60 ins., cross compound condensing, complete, including foundations, condenser, all necessary pumps, all piping, boilers, and stack or chimney for induced draft.

Steam Boilers. We are indebted to L. P. Breckenridge, Professor of Mechanical Engineering at the Sheffield Scientific School, Yale University, for the following formulæ of costs.

Type	Capacity	Equation of cost in dollars
Horizontal water tube	Up to 500 hp.	$400 + 8 \times$ hp.
Vertical water tube	Up to 500 hp.	$300 + 7 \times$ hp.

A. A. Potter, Professor of Steam and Gas Engineering, has given in Power, Dec., 1913, the following formulæ of costs.

Type	Capacity, boiler, h.p.	Equation of cost, dol.
Vertical fire tube	Under 20 hp.	$49.2 + 6.66 \times$ hp.
Submerged tubes, 100 lb. per sq. in.	20 to 50 hp.	$116.4 + 3.35 \times$ hp.
Full length tubes, 100 lb. per sq. in.	Up to 50 hp.	$51.5 + 3.62 \times$ hp.
Horizontal fire-tube cylindrical	Up to 50 hp.	$64. + 4.14 \times$ hp.

From Bulletin No. 2 of Kansas State Agricultural College entitled Boiler-Room Economics by A. A. Potter and S. L. Simmering we have taken the following:

Portable locomotive type fire-tube boilers, $C = 121 + 5.68 \times$ hp., where C = cost in dollars and hp. = boiler horse-power.

Horizontal fire-tube boilers — working pressure, 125 lb. gauge; for 100 hp. or less, $C = 5.8 \times$ hp. — 20 from 100 to 225 hp., $C = 211 + 3.35 \times$ hp.

Vertical water-tube boilers; upper limit, $C = 1032 + 2.68 \times$ hp.; lower limit, $C = 797 + 6.17 \times$ hp.; average cost, $C = 912 + 6.98 \times$ hp.

Horizontal water-tube boilers, $C = 149 + 8.24 \times$ hp.

Tables LXX–LXXIV were compiled by A. A. Potter and S. L. Simmering from data furnished them by manufacturers. From these tables were deduced the formulæ from Bulletin No. 2, above.

TABLE LXX. COST DATA FOR VERTICAL FIRE-TUBE BOILERS — FULL LENGTH TUBES, FOR WORKING PRESSURES OF 100 LB. PER SQ. IN. OR LESS

Boiler hp.	Size of shell, in.	Weight, lb.		Heating surface sq. ft.		Grate area sq. ft.		Ratio heat surf. to grate	Cost, dollars		
		Total	Per hp.	Total	Per hp.	Total	Per hp.		Total	Per hp.	Per lb.
5	24 by 33	1,050	210	48.75	13.75	2.3	0.46	21.6	$72	$14.40	$0.0686
6	24 by 30	....	....	57	9.5	2.	0.33	28.5	72	12.00	....
8	30 by 33	....	....	76	9.5	3.54	0.44	21.5	79	9.88	....
10	30 by 48	1,600	160	108	10.8	3.54	0.354	30.5	95	9.50	0.0594
15	36 by 48	2,150	143.3	153	10.2	5.37	0.358	28.5	108	7.20	0.0502
20	36 by 66	2,400	120	206.7	10.3	5.37	0.269	20	127	6.35	0.053
25	42 by 60	2,950	118	271.8	10.9	7.62	0.304	24.9	154	6.16	0.0522
30	42 by 66	3,100	106.5	297.5	9.9	7.6	0.254	39.2	165	5.50	0.0533
35	42 by 78	....	....	349.2	10	7.61	0.22	45.9	169	4.83	....
40	48 by 66	3,950	99	388.2	9.7	9.8	0.254	39.6	206	5.12	0.052
50	48 by 90	4,700	94	522.2	10.44	9.8	0.2	50	238	4.76	0.0476

TABLE LXXI. COST DATA FOR PORTABLE, LOCOMOTIVE TYPE, FIRE-TUBE BOILERS

Boiler hp.	Size of shell, ins.	Weight, lbs		Grate area sq. ft.		Cost, dollars		
		Total	Per hp.	Total	Per hp.	Total	Per hp.	Per lb.
15	32 by 72	3,900	260	8	0.53	218	14.53	0.056
25	36 by 96	5,250	210	10.4	0.43	271	10.82	0.0516
40	42 by 120	7,200	180	12.5	0.31	348	8.70	0.0484
60	48 by 144	11,200	187	18	0.30	490	8.17	0.0438
80	54 by 168	13,900	173.8	22.7	0.28	590	7.38	0.0425
100	60 by 168	16,900	169	25.5	0.26	710	7.10	0.042

TABLE LXXII. COST DATA FOR HORIZONTAL FIRE-TUBE BOILERS, FOR WORKING PRESSURE OF 120 LB. PER SQ. IN.

Boiler hp.	Size of shell, in. and ft.	Weight, lb. Total	Weight, lb. Per hp.	Heating surface, sq. ft. Total	Heating surface, sq. ft. Per hp.	Grate area, sq. ft. Total	Grate area, sq. ft. Per hp.	Ratio heat surf. to grate	Cost, dollars Total	Cost, dollars Per hp.	Cost, dollars Per lb.
50	48 by 14	6,500	130	553	11.06	16	0.333	34.5	270	5.40	0.0415
60	54 by 14	8,100	135	728	12.3	18	0.300	40.5	332	5.54	0.041
70	54 by 16	9,000	129	828	11.8	20	0.290	41.4	360	5.14	0.040
75	60 by 14	......	...	879	11.7	22.5	0.300	39	390	5.20	....
80	60 by 16	11,100	139	999	12.5	22.5	0.280	44.3	435	5.43	0.039
90	60 by 18	12,400	138	1,119	12.4	25.	0.28	44.8	457	5.09	0.0403
100	66 by 16	13,500	135	1,137	11.4	27.5	0.28	41.3	536	5.36	0.0398
125	72 by 16	16,700	134	1,430	11.4	32.5	0.26	44	630	5.04	0.0378
150	72 by 18	18,300	122	1,602	10.7	36	0.24	44.5	682	4.54	0.0373
175	78 by 18	......	...	2,019	11.45	36	0.206	55.7	770	4.40	.....
175	78 by 18	......	...	2,019	11.45	36	0.206	55.7	805	4.60	.....
200	78 by 20	25,000	125	2,236	11.18	39	0.195	57.3	931	4.66	0.0372

TABLE LXXIII. COST DATA FOR VERTICAL WATER-TUBE BOILERS, FOR WORKING PRESSURES OF 125 LB. PER SQ. IN. OR LESS

Boiler hp.	Tubes No.	Tubes Size, in.	Weight lbs. Total	Weight lbs. Per hp.	Heating surface, sq. ft. Total	Heating surface, sq. ft. Per hp.	Grate area, sq. ft. Total	Grate area, sq. ft. Per hp.	Ratio heat surf. to grate	Cost, dollars Total	Cost, dollars Per hp.	Cost, dollars Per lb.
100	64	4	24,300	243	1,117	11.17	22.5	0.225	49.6	1,824	18.24	0.075
150	80	4	29,700	198	1,543	10.29	27.5	0.183	56.2	2,149	14.27	0.072
200	94	4	37,300	186.5	2,014	10.07	36	0.18	56	2,380	11.90	0.0638
250	112	4	44,900	179.4	2,510	10.04	42	0.168	59.8	2,682	10.73	0.0597
260	...	..	.....	....	....	....	...	....	...	2,450	9.42	.....
300	...	..	.....	....	....	....	...	....	...	2,890	9.63	.....
325	...	..	.....	....	....	....	...	....	...	3,002	9.23	.....
350	...	..	.....	....	....	....	...	....	...	3,330	9.51	.....
400	...	..	.....	....	....	....	...	....	...	3,500	8.75	.....
450	...	..	.....	....	....	....	...	....	...	3,815	8.48	.....
475	...	..	.....	....	....	....	...	....	...	4,200	8.84	.....

TABLE LXXIV. COST DATA FOR HORIZONTAL WATER-TUBE BOILERS. FOR WORKING PRESSURES OF 125 LB. PER SQ. IN. OR MORE

Boiler	Tubes		Weight, lb.		Heating surface, sq. ft.		Grate area sq. ft.		Ratio heat surf.	Cost, dollars		
hp.	No.	Size, in.	Total	Per hp.	Total	Per hp.	Total	Per hp.	to grate	Total	Per hp.	Per lb.
50	32	..	16,700	334	508	10.16	13.5	0.27	37.7	950	19.00	0.0568
50	...	..	9,500	190	....	...	17	0.34	...	600	12.00	0.0632
72	40	..	19,400	270	715	9.94	16.5	0.229	43.3	1,065	14.80	0.055
72	...	..	14,000	187	....	...	21	0.28	...	750	10.00	0.0535
75	...	..	.....	....	....	...	...	...	...	1,050	14.00	.....
102	54	..	26,700	252	1,018	9.98	26	0.255	39.2	1,250	12.25	0.0468
98	53	3.5	.....	....	980	10	20.3	0.208	49	1,225	12.50	.....
100	...	..	18,000	180	....	...	28	0.28	...	1,000	10.00	0.0556
100	...	..	.....	....	....	...	...	...	...	1,150	11.50	.....
125	...	..	.....	....	....	...	...	...	...	1,408	11.26	.....
123	68	3.5	.....	....	1,230	10	24.7	0.2	49.8	1,375	11.18	.....
150	...	..	20,500	136.5	....	...	31	0.207	...	1,350	9.00	0.066
148	80	..	34,500	233	1,478	10	34	0.23	43.5	1,620	10.95	0.047
150	...	..	.....	....	....	...	...	....	...	1,650	11.00	.....
155	94	3.5	.....	....	1,550	10	30.4	0.196	51	1,590	10.25	.....
170	94	3.5	.....	....	1,700	10	32.9	0.194	51.6	1,640	9.65	.....
175	...	..	.....	....	....	...	...	....	...	1,880	10.74	.....
200	100	..	41,700	208.5	1,986	9.93	42	0.21	47.3	2,038	10.19	0.0488
205	127	3.5	.....	....	2,050	10	40.6	0.198	50.6	1,780	8.70	.....
200	...	..	28,000	140	....	...	40	0.20	...	1,800	9.00	0.0644
200	...	..	.....	....	2,000	10	44	0.22	45.5	2,050	10.25	.....
200	...	..	.....	....	....	...	...	...	...	2,450	12.25	.....
244	138	3.5	.....	....	2,440	10	48.4	0.188	50.5	2,050	8.40	.....
308	190	3.5	.....	....	3,080	10	56.1	0.182	55	2,380	7.74	.....
290	132	..	56,000	193	2,888	9.98	58.3	0.201	49.5	2,842	10.14	0.0508
360	160	..	68.500	190	3.598	10	77	0.214	46.7	3,330	9.26	0.0486
357	202	3.5	.....	....	3,570	10	64.4	0.18	55.6	2,800	7.85	.....
391	176	..	72,900	186.4	3,911	10	77	0.197	50.75	3,610	9.25	0.0495
400	254	..	.....	....	4,000	10	82	0.205	48.8	3,410	8.53	.....
455	208	..	80,800	177.4	4,537	9.98	82.5	0.181	55	3,980	8.46	0.0493
463	254	3.5	.....	....	4,630	10	92.8	0.2	50	3,710	8.02	.....
500	...	..	.....	....	5,000	10	...	...	...	5,000	10.00	.....
500	...	..	.....	....	5,000	10	...	...	...	5,750	11.50	.....
514	276	3.5	.....	....	5,140	10	100.3	0.197	49.8	4,125	8.03	.....
564	...	..	.....	....	5.640	10	107.5	0.191	52.4	4,305	7.65	.....
593	326	3.5	.....	....	5,930	10	108	0.183	54.8	4,485	7.57	.....

Cost of Boilers. From the American Handbook for Electrical Engineers we take the following: The selling price of boilers per rated h.p. (10 sq. ft. of heating surface = 1 h.p.) ranges from about $8 to $25, depending upon the size, the pressure they are to sustain, the style and design, etc. The lowest prices named are for large-sized, ordinary, horizontal tubular boilers (fire tube) for low pressure. For power plants of 1000 h.p. and over the price will range usually between $10 and $15 for pressures not over 150 lbs. per sq. in. For higher pressures and for boilers provided with superheaters the prices will be higher. For boilers of less than 100 h.p. the price per h.p. increases as the size decreases. The prices named are for the boilers with the usual fittings of grates, steam and water gauges, blowoff and stop valves, on board cars at the boiler works, and do not include the cost of erection nor of brickwork, flues or chimneys.

C. H. Benjamin (Eng. News, Nov. 15, 1902) gives the following rules for estimating the cost of boilers; P = boiler horsepower; the cost is in dollars.

(1) Horizontal water-tube boilers, 125 lbs. pressure, 10 sq. ft. of heating surface per boiler hp.
Cost of boiler = 500 + 9.20 P.
" " setting = 400 + 0.80 P.

(2) Vertical water tube boiler as in (1).
Cost of boiler = 500 + 8.50 P.

(3) Horizontal return tubular boilers, 12 sq. ft. of heating surface per horse-power.
Cost of boiler = 100 + 6.50 P.
" " setting = 300 + 0.70 P.

Boilers. The manager of a reputable boiler works has given us the following general data: Cost of water tube boilers f.o.b. factory varies from $8 per h.p. for larger size units to $12 for small size units.

The cost of boiler installations varies widely according to specifications. An average installation costs complete $15 to $20 per h.p., the smaller sizes costing more per h.p. than the large sizes. However, with exceptionally fine fittings, etc., even large installations may run as high as from $20 to $25 per h.p.

Boilers. The following information was taken from The Isolated Plant, Dec., 1909. Horizontal return tubular boilers cost from $9 to $10, including the setting per h.p.; the boiler itself costing between $6 and $7 per h.p. This does not include fittings, valves or pipe connections.

Water tube boilers cost from $14 to $16 per h.p., including setting, or about $10 per h.p. without setting.

Water-tube Boilers. The following costs of water-tube boilers and settings are the average of prices for boilers and costs of settings obtained in connection with our appraisals throughout the United States. The prices are those of 6 standard manufacturers of boilers and there is a variation of 15% above and below the average given. In the cost of settings there is a variation of 20% above and below the average.

WATER TUBE BOILERS

Size, hp.	Weight, lb.	Net price of boiler, f.o.b. works	Cost of boiler and setting complete
100	20,000	$1,125	$1,550
200	40,000	2,000	2,600
250	51,000	2,440	3,100
300	62,000	2,830	3,500
400	82,000	3,600	4,350
500	103,000	4,350	5,150
600	125,000	5,100	5,950
800	168,000	6,450	7,400
1,000	210,000	7,800	8,800

UPRIGHT MANNING TUBULAR BOILER

Size, hp.	Weight, lb.	Net price f.o.b. factory
5	1,500	$172
10	1,950	195
15	3,500	300
20	4.500	360
25	5,000	390
30	5,300	400
35	6,000	440
40	6,650	480
50	8,500	560
60	11,000	690
75	12,500	770
100	15,000	900
120	21,000	1,200
150	26,000	1,430
225	41,000	2,180
275	48,000	2,500
325	55,000	2,800
380	60,000	3,000
415	65,000	3,120

HORIZONTAL RETURN TUBULAR BOILER

Size, hp.	Weight lb.	Net price
16	3,100	$270
29	4,600	270
48	6,600	470
78	8,600	575
99	12,000	745
130	14,800	890
171	19,700	1,130
205	23,000	1,310
249	29,000	1,600
315	37,000	1,960
355	42,000	2,180

Average Cost of Horizontal Tubular Boilers, Accessories, Connections, Settings. Judson H. Boughton in Engineering Magazine, November, 1907, quotes Isherwood for the following figures reduced to a horse-power basis, in comparing the performances of the two-general types of boilers.

Water-tube: 11 sq. ft. heating surface, 3.3 lbs. of coal; relative economy 100, relative rate of steaming 100.

TABLE LXXV. COST OF HORIZONTAL TUBULAR BOILERS

Tubular boilers, hp.	30	50	60	70	80	90	100	125	150
Aver. size of boiler	44 in. by 12 ft.	54 in. by 14 ft.	54 in. by 16 ft.	60 in. by 14 ft.	60 in. by 16 ft.	66 in. by 15 ft.	66 in. by 16 ft.	72 in. by 16 ft.	78 in. by 18 ft.
Aver. cost, boiler and fixtures, full front	$405	$595	$670	$725	$810	$940	$975	$1,010	$1,370
Aver. iron stack and raising	60	95	98	110	120	125	130	150	240
Aver. boiler setting, masonry	185	240	260	297	300	305	310	385	450
Aver. hauling	15	15	15	20	30	30	30	30	40
Aver. cost of boiler set	$665	$945	$1,043	$1,162	$1,270	$1,400	$1,440	$1,575	$1,970
Aver. feed-water heater	55	90	90	105	120	140	140	220	220
Aver. boiler-feed pump	55	70	70	70	90	110	110	125	145
Aver. injector	14	14	14	18	18	20	20	24	28
Aver. piping, including engine connections	75	105	115	130	140	185	195	245	310
Aver. pump and heater foundations	14	18	18	18	21	21	21	21	28
Aver. total cost, boiler, stack, heater, pump, set and connected	$878	$1,242	$1,350	$1,503	$1,659	$1,876	$1,926	$2,210	$2,701

Horizontal Tubular: 16 sq. ft. of heating surface, 4.0 lbs. of coal; relative economy 91, relative rate of steaming 50.

The average cost of different sizes of boilers of the horizontal tubular type, which type has been more generally used especially in smaller plants, including also cost of accessories and connections and of setting is given in Table LXXV; 5 to 7% is a fair reduction to make from these figures for each boiler set in battery.

Average Cost of Water-Tube Boilers, Including Setting and Fittings, but Without Mechanical Stokers or Economizers. W. H. Weston, Engineering Magazine, January, 1912, has given the following table.

H.p.	Cost
400	$ 5,500
600	7,500
800	9,500
1000	11,500
1500	15,500
2000	20,000
4000	38,000

He states that the average cost of inside-firebox boilers of 200 h.p. and upward is $0.12 to $0.14 per lb. f.o.b. the boiler shop for boilers of standard construction. These figures and those of the table are on a compound condensing basis.

Floor Area Occupied by Fire-Tube and Water-Tube Boilers. The following data are from Bulletin No. 2, Boiler Room Economics, by A. A. Potter and S. L. Simmering of Kansas State Agricultural College. The space occupied by any given boiler, or the cost of its setting, will not be altered by driving the boiler above its rated capacity. Operating a boiler at an overload results in a decreased cost per sq. ft. of floor area per h.p. Where real estate, foundations, and buildings are expensive, these items sometimes exceed the cost of the bare boilers.

C. R. D. Meier, in comparing the costs of various plants, in a paper read before the Associated Engineering Societies of St. Paul, gives the following:

Real estate, cost per sq. ft.	$0.25 to $10.00
Foundations, " " " "	1.25 " 4.00
Buildings, " " " "	2.00 " 8.00

This gives a minimum cost of $3.50 and a maximum cost of $22 per sq. ft. of floor area.

To determine the floor area occupied by various types of fire-tube boilers, including settings, the rated horsepowers and floor areas were plotted and Table LXXVI deduced from these plots.

The average dimensions for a number of standard fire-tube boiler settings are:

45 h.p.	7 ft. 7 in. by	16 ft. 6 in. by	8 ft. 2 in. high
80 "	8 " 10 " "	21 " 3 " "	9 " 2 " "
100 "	9 " 6 " "	21 " 3 " "	10 " 2 " "
150 "	10 " 2 " "	23 " 8 " "	10 " 8 " "
200 "	11 " 0 " "	25 " 10 " "	11 " 0 " "
240 "	11 " 3 " "	25 " 10 " "	11 " 2 " "

The space occupied by a given area of water-tube surface will be determined by the size and length of tubes, the spacing and arrangement of tubes, and the general design of the boiler. With vertical baffles, three- and four-pass boilers, the tubes are usually 4 ins. in diam., staggered with centers about 8 ins. apart in the horizontal rows and 10 ins. on the vertical rows. With horizontal baffles, the tubes are usually 3.5 ins. in diam. and arranged on equal centers horizontally and vertically. Comparing a number of water-tube boilers the floor space occupied varied from 1.62 sq. ft. for a 150-h.p. boiler to 0.55 sq. ft. for a 625-h.p. boiler. The total floor space per b.h.p. occupied by any boiler decreases as the rated h.p. of the unit increases.

Settings For Fire-Tube Boilers. From Bulletin No. 2, Kansas State Ag. College, we have also taken the following. The approximate number of fire brick and common brick required for various sizes of fire-tube boilers will be found in Table LXXVI.

TABLE LXXVI. FLOOR SPACE OCCUPIED BY FIRE-TUBE BOILER SETTINGS

Rated h.p.	Sq. ft. floor space per rated h.p.
50	2.73
75	2.36
100	2.01
125	1.77
150	1.60
175	1.48
200	1.38
225	1.30
250	1.22

When two or more boilers are set in a battery the number of brick required will depend largely upon the method of constructing the inner walls, also whether the boilers are suspended from overhead steel framework or are supported by the walls.

Experiments by the U. S. Bureau of Mines (Bulletin No. 8) show that for boiler settings a solid brick wall is preferable to the hollow wall, especially if the air space in the hollow wall is near the furnace side. If the wall must be built in two parts, the space should be filled with ash, crushed brick or sand, as loose material reduces air leakage.

The cost of brick boiler settings exclusive of the foundation may be estimated at about $25 per 1000 brick laid (see Gillette's Handbook of Cost Data for details as to cost of brick masonry).

TABLE LXXVII. BRICK REQUIRED FOR FIRE-TUBE BOILER SETTINGS

Size of boiler	Approximate no. brick Fire brick	Common brick
48 in. by 12 ft.	880	10,640
54 " " 14 "	1,540	13,500
60 " " 16 "	1,700	17,300
66 " " 16 "	1,880	19,200
72 " " 18 "	2,270	21,850

Boiler Tubes. The following prices are for tubes up to 20 ft. in length.

Diam. ins.	Weight, lbs. per ft.	Net price per ft.
1¾	1.679	$0.099
2	1.932	0.09
2¼	2.186	0.099
2½	2.783	0.112
2¾	3.074	0.1085
3	3.365	0.119
3¼	4.011	0.14
3½	1.331	0.14
3¾	4.652	0.153
4	5.532	0.179
4½	6.248	0.201

Flue Cleaners.

THE "INGALLS" SELF ADJUSTING TUBE SCRAPER

Diam., ins.	Net price per in.
	$0.60

THE COMBINATION SCRAPER AND BRUSH

Diam., ins.	Net price per in.
1½–4½	$0.75

LAGONDA THRUST BEARING TUBE CLEANER MACHINES

Diam., ins.	Net price
2, 2½	$50
3¼	60
3½–4	75

LAGONDA AIR AND STEAM CLEANERS

Diam., ins.	Net price
2, 2½, 3¼	$60
3½–4	75

SPECIAL HOSE FOR OPERATING FLUE CLEANERS

Diam., ins.	Net price per ft.
1	$0.30
1¼	0.40
1½	0.50

Steel Cooling Towers with Fans Complete. W. H. Weston, Engineering Magazine, January, 1912, has given the following table.

H.p.	Approximate cost
500	$1,700
1,000	3,000
2,000	5,000
4,000	9,000

Natural-draft towers may cost a little less than these, which represent a fair average for well constructed and efficient towers. The h.p. is figured on compound condensing basis.

Condensers. A. A. Potter, Power, Dec. 30, 1913, gives the following formulæ of costs.

Type		Capacity
A Barometric	(28-in. vacuum)	Up to 30,000 lbs. of steam per hr.
B Jet condensers	(28-in. vacuum)	" " 30,000 " " " " "
C Jet condensers	(26-in. vacuum)	" " 30,000 " " " " "
D Surface condensers	(28-in. vacuum)	" " 35,000 lbs. per hr.
E Surface condensers	(26-in. vacuum)	" " 30,000 " " "

Type	Equation of cost in dollars
A	$1055 + 0.112 \times$ (lb. cond. steam)
B	$1176 + 0.1138 \times$ (" " ")
C	$116 + 0.0591 \times$ (" " ")
D	$1630 + 0.2038 \times$ (" " ")
E	$413 + 0.1015 \times$ (" " ")

An approximate formula that is sometimes used for determining the cost of jet condensers is,

$$\text{Cost in dollars} = 500 + 1.0 \times \text{h.p.}$$

Cost of Economizers. A. A. Potter, in Power, Dec. 30, 1913, gives the following as a guide in estimating the cost of apparatus and erection. Number of tubes, 32 to 10,000; heating surface per tube, 12 to 13 sq. ft.; capacity in lbs. of water per tube, 60 to 70; cost of economizer, f.o.b. factory, \$8 to \$10 per tube; cost, erected, \$12 to \$15 per tube.

J. F. C. Snell gives for the cost of economizers \$1.40 per kw., including brick work, or \$70 per 1000 lbs. of normal evaporation of the boilers.

The Cost of Fuel Economizers. The following data were furnished by the Green Fuel Economizer Co. Economizers cost on the average from \$4 to \$6 installed per h.p. of boilers, \$6 being the maximum, but under favorable conditions the cost is considerably less and installations have been made for less than \$3. The price of economizers f.o.b. the factory, for plants of 600 h.p. would be about \$2,400 and for 1,800 h.p. \$6,500.

The cost of installing the smaller plant, under average conditions, is about \$500, and the larger, \$1,000.

Economizers. W. H. Weston, Engineering Magazine, Jan., 1912, says that for 500 h.p. or more, the average cost of economizers, figured on compound condensing basis and including settings and scraping equipment, is about \$4 per h.p.

Cost of Duplicate Induced Mechanical-Draft Equipment Installed. W. H. Weston, Engineering Magazine, January, 1912, has given the following table, figured on compound-condensing basis.

H.p.	Cost
800	\$1,600
1,000	1,800
1,500	2,250
2,000	2,275
4,000	5,000

Cost Formulae for Reciprocating Steam Engines. A. A. Potter gives the formulae in Table LXXVIII (Power, Dec. 30, 1913).

TABLE LXXVIII. COST OF SIMPLE STEAM ENGINES

Type	Capacity	Equation of cost, dollars
Throttle governor, slide valve, vertical	Up to 70 h.p.	63.5 + 17.5 × h.p.
" " " " horizontal	Up to 70 h.p.	107 + 13.3 × h.p. Max.
" " " " "	Up to 200 h.p.	80 + 5.81 × h.p. Min.
Flywheel governor, piston or balanced slide valve, horizontal	Up to 500 h.p.	386 + 6.69 × h.p.
Automatic cut-off, single valve, vertical	Up to 30 h.p.	164 + 9.53 × h.p.
" " " " " "	30 to 150 h.p.	372.5 + 9.55 × h.p.
Flywheel governor, Corliss non-releasing valve, horizontal	Up to 600 h.p.	1100 + 8.94 × h.p.
Corliss governor and valves, horizontal	Up to 400 h.p.	1040 + 8.45 × h.p.
" " " " "	300 to 900 h.p.	730 + 9.1 × h.p.
Flywheel governor, multiple flat valves	Up to 400 h.p.	685 + 7.69 × h.p.

CROSS COMPOUND STEAM ENGINE

Type	Capacity	Equation of cost, dollars
Ball governor, single-valve, horizontal	Up to 330 h.p.	735 + 8.0 × h.p.
" " " " vertical	Up to 200 h.p.	750 + 10.4 × h.p.
Flywheel governor, multiported valves, horizontal	Up to 600 h.p.	1100 + 9.62 × h.p.
Shaft governor, Corliss non-releasing valves, horizontal	Up to 600 h.p.	2015 + 9.74 × h.p.

TANDEM COMPOUND STEAM ENGINES

Type	Capacity	Equation of cost, dollars
Flywheel governor and slide valve, horizontal	Up to 400 h.p.	559 + 8.83 × h.p.
" " " " " vertical	Up to 140 h.p.	610 + 12.7 × h.p.
Flywheel governor, Corliss non-releasing valves, horizontal	Up to 300 h.p.	1295 + 10.79 × h.p.
Flywheel governor, multiple slide-valves	Up to 500 h.p.	1010 + 7.65 × h.p.

TABLE LXXIX. COST OF CORLISS, SINGLE CYLINDER ENGINES

Size of cylinder	Hp. 80 lb., .25 stroke	Cost: Engine	Cost: Foundation	Cost: Erecting	Cost: Piping	Cost: Total	Approx. hp. of engine	Heater: Price, brass tubes	Feed pump: Price, pump alone	Feed pump: Price, with connections	Injector: Price, injector alone	Injector: Price, with connections
14 by 36....	100	$1,700	$275	$175	$165	$2,315	20	$47	$70	$84	$20	$77
14 by 42....	110	1,800	300	200	175	2,475	35	74	80	93	20	82
16 by 36....	125	1,950	325	210	180	2,665	60	107	80	140	20	109
16 by 42....	140	2,000	350	225	190	2,765	70	134	127	190	28	110
18 by 36....	155	2,150	375	240	200	2,965	80	134	127	196	28	111
18 by 42....	175	2,350	400	250	210	3,210	100	161	127	196	30	126
18 by 48....	200	2,600	425	260	220	3,505	110	161	127	196	30	135
20 by 42....	210	2,600	500	270	230	3,600	125	200	143	253	30	135
20 by 48....	230	2,850	525	275	250	3,900	140	200	143	253	38	166
22 by 42....	250	3,000	550	300	310	4,160	150	200	143	253	38	166
22 by 48....	280	3,300	600	325	340	4,565	160	332	143	253	38	166
24 by 48....	320	4,000	700	375	390	5,465	170	332	143	253	38	166
26 by 48....	380	4,650	800	440	560	6,450	200	332	143	268	45	191
28 by 48....	425	5,150	900	500	800	7,650	225	332	143	268	45	191
28 by 54....	480	5,300	1,050	575	950	7,875	250	...	143	...	45	...
30 by 48....	490	5,800	1,200	600	1,070	8,670	300	...	143	...	55	...
30 by 60....	560	7,000	1,400	700	1,140	10,240	400	...	187	...	65	...

20% above and below the average.

TABLE LXXX. COST OF HIGH-SPEED SINGLE-CYLINDER ENGINES

High-speed engine — hp.	50	75	100	125	150	200	250
Size of cylinder, in.	9 by 10	10 by 12	12 by 12	13 by 14	{15 by 14 / 14 by 16}	18 by 16	19 by 18
Steam pressure	100	100	100	100	100	100	100
Rev. per min.	300	300	290	275	245	225	200
Cost delivered	$695	$890	$1,085	$1,260	$1,595	$2,010	$2,800
Sub-base	45	50	50	70	80	90	250
Engine foundation	65	75	80	95	110	140	200
Superintendence — labor	70	70	70	70	75	85	100
Handling	10	15	15	17	20	25	35
Total cost of engine set up on foundation	$885	$1,100	$1,300	$1,512	$1,880	$2,350	$3,385

TABLE LXXXI. COST OF CORLISS COMPOUND CONDENSING ENGINES

Capacity, hp.	Speed, rev. per min.	Steam pressure, lb.	High pressure cylinder Low pressure cylinder Stroke	Cost	Steam pressure, lb.	High pressure cylinder Low pressure cylinder Stroke	Cost	Foundation and erecting	Weight complete, lb.
200	80	100	14 by 28 by 42	$4,565	120	13 by 26 by 42	$4,465	$1,050	60,000
300	75	100	18 by 34 by 42	5,700	120	16 by 32 by 42	5,500	1,025	85,000
400	75	100	20 by 38 by 48	7,300	120	18 by 36 by 48	7,100	1,250	110,000
500	75	100	22 by 42 by 48	8,480	120	20 by 40 by 48	8,280	1,400	140,000
600	75	100	24 by 46 by 48	10,100	120	22 by 44 by 48	9,900	1,675	170,000

TABLE LXXXII. COST OF HIGH-SPEED COMPOUND ENGINES

	H.p. at 100 lbs. steam pressure									
Horse power	60	80	100	125	150	200	250	300	350	400
High pressure cylinder	8 in.	9 in.	10 in.	11 in.	12 in.	13 in.	15 in.	16 in.	17 in.	20 in.
Low pressure cylinder	13 "	16 "	18 "	19 "	20 "	22 "	25 "	28 "	30 "	36 "
Stroke	12 "	12 "	12 "	14 "	16 "	16 "	16 "	18 "	18 "	18 "
Price	$1,070	$1,300	$1,400	$1,690	$2,145	$2,470	$2,730	$3,380	$3,900	$4,290
Sub-base	120	120	120	140	140	150	160	200	250	300
Total	$1,190	$1,420	$1,520	$1,830	$2,285	$2,620	$2,890	$3,580	$4,150	$4,590

Prices and Cost of Setting up Corliss Single-Cylinder Engines, Set-up and Connected. Tables LXXIX-LXXXII are after J. H. Boughton, Engineering Magazine, November, 1907.

Mr. Boughton considers that the investment represented by the Corliss engine with the necessary shafting, pulleys, and belting may ordinarily be taken as double that of the high-speed engine.

The Corliss requires 3 lbs. of coal per h.p. as against from 4 to 5 lbs. by the high-speed type.

This includes condensers and the prices given apply to both tandem and cross-compound engines, the price of the former being less than 10% lower in smaller sizes and sometimes greater in large sizes.

Average Cost of Engines, Including Surface Condensers, Air and Circulating Pumps. W. H. Weston, Engineering Magazine, January, 1912, has given the following table.

H.p.	Cost
400	$9,500
500	11,500
600	13,500
800	18,000
1,000	22,000
1,500	32,000
2,000	42,000
4,000	80,000

Prices and Weights of Miscellaneous Accessories. The following prices were in effect prior to the war.

SCOTCH GAUGE GLASSES

Length, in.	External diam., in. ½ & ⅝	¾	⅞	1
10	$0.45	$0.54	$0.76	$0.92
11	0.49	0.59	0.86	1.01
12	0.54	0.65	0.92	1.10
13	0.58	0.72	0.99	1.19
14	0.63	0.78	1.06	1.28
15	0.68	0.83	1.13	1.37
16	0.72	0.88	1.23	1.46
17	0.75	0.94	1.29	1.55
18	0.81	0.99	1.37	1.64

The above are net prices per dozen.

THE FISHER REGULAR GOVERNOR

SCREWED CONNECTIONS

Size, in.	Shipping wt., lb.	Net price
½	15	$15.50
¾	16	19.00
1	35	21.00
1¼	37	25.00
1½	56	30.00
2	60	35.00
2½	75	40.00
3	100	49.00

FLANGED CONNECTIONS

Size, ins.	Shipping wt., lbs.	Net price
1½	75	$33
2	87	36
2½	120	44
3	130	55
3½	150	63
4	178	74
5	200	91
6	225	110
8	300	160

CAST IRON EXHAUST HEADS

Size of exhaust pipe, in.	Weight, lb.	Net price
1	30	$10.50
1½	30	10.50
2	35	13.20
2½	35	13.20
3	50	13.50
3½	50	13.50
4	70	18.00
4½	70	18.00
5	80	22.20
6	135	27.00
7	140	31.20
8	160	40.50
9	175	45.00
10	250	63.00
12	300	72.00
14	400	99.00
16	500	120.00
18	600	150.00
20	700	180.00
22	950	210.00
24	1,050	225.00
26	1,150	240.00
30	1,700	330.00
36	2,300	435.00

Feed-Water Heaters. A. A. Potter, Power, Dec. 30, 1913, gives the following formulæ for determining costs.

Type	Capacity	Equation of cost, dollars
Open	Up to 1500 boiler hp.	$114.5 + 0.3787 \times$ hp.
Open	1500 to 3000 boiler hp.	$326 + 0.237 \times$ hp.
Closed	Up to 3000 boiler hp.	$40 + 0.72 \times$ hp.

These formulæ were deduced from the manufacturers' selling prices. The following tables are from Bulletin No. 2, Kansas State Agricultural College, Boiler Room Economics, by A. A. Potter and S. L. Simmering.

TABLE LXXXI. COST DATA FOR OPEN FEED-WATER HEATERS

Boiler hp.	Cost	Per hp.	Boiler hp.	Cost	Per hp.
50	$75	$1.50	800	$430	$0.54
100	92	0.92	900	500	0.56
200	158	0.79	1,000	478	0.47
300	229	0.76	1,200	510	0.43
400	255	0.64	1,500	680	0.45
500	313	0.63	2,000	800	0.40
600	339	0.56	2,500	920	0.37
700	410	0.57	3,000	1,000	0.33

TABLE LXXXII. COST DATA FOR CLOSED FEED-WATER HEATERS

Boiler hp.	Total	Per hp.	Boiler hp.	Total	Per hp.
5	$10	$2.00	300	250	0.83
10	12	1.18	400	310	0.78
20	25	1.25	250	210	0.84
25	27	1.08	500	360	0.72
30	37	1.23	700	511	0.73
40	48	1.20	800	650	0.81
50	51	1.02	1,000	730	0.73
60	64	1.07	1,500	1,050	0.70
80	68	0.85	2,000	1,325	0.66
100	87	0.87	2,500	1,825	0.73
125	99	0.79	3,000	2,000	0.67
150	122	0.81	4,000	2,520	0.63
200	$170	$0.85	5,000	3,155	0.63

Average Cost of Feed-Water Heaters. W. H. Weston has given the following data in The Engineering Magazine, Jan., 1912, for compound-condensing plants.

Hp. of plant	Cost of feed-water heaters completely installed	Hp. of plant	Cost of feed-water heaters completely installed
400	$800	1,000	$1,100
500	875	1,500	1,400
600	900	2,000	1,800
800	1,000	4,000	3,000

OPEN FEED-WATER HEATERS

From data furnished by a manufacturer.

Hp.	Net price	Hp.	Net price
50	$75	1,200	$550
75	80	1,400	620
100	95	1,500	645
200	160	1,600	675
300	220	1,800	740
400	270	2,000	800
600	360	2,200	840
700	400	2,400	890
800	425	2,600	940
900	460	2,800	980
1,000	490	3,000	1,025
1,100	530	3,200	1,060

CLOSED FEED-WATER HEATERS

Hp.	Weight, lb.	Net price
5	35	$9
10	65	12
15	80	16
20	180	23
25	270	27
30	350	35
40	390	41
50	420	50
60	475	60
80	515	22
100	800	82
125	850	95
150	1,150	113

Hp.	Weight, lb.	Net price
200	1,300	150
250	1,450	180
300	1,650	230
400	1,900	270
500	2,200	340
600	2,800	410
700	3,000	475
800	3,200	540
1,000	5,100	675
1,250	5,600	810
1,500	5,900	950
2,000	9,400	1,260
2,500	10,500	1,575
3,000	11,500	1,890
4,000	13,500	2,510
5,000	15,500	3,150

Cost of Injectors. From Bulletin No. 2, Kansas State Agricultural College, Boiler Room Economics, by A. A. Potter and S. L. Simmering we have taken the following. Tables LXXXIII–LXXXVI give the cost of injectors based upon their capacity in gallons per minute, and also the boiler h.p. for which the injector is intended. Injectors are classified as follows: (a) single-tube injectors; (b) double-tube injectors; (c) restarting injectors. Table LXXXVII shows the relative costs of the 4 types of injectors for various capacities.

The following are equations deduced from Tables LXXXIII–LXXXVI. G represents the capacity in gallons per minute and C the cost in dollars.

For a single-tube injector .... $C = 2.62 + 0.79 \times G$.
For a double-tube injector .... $C = 4 + 0.8 \times G$.
For a restarting tube injector, capacities less than 10 gal. per min. .... $C = 3.4 + 1.26 \times G$.
Capacities from 10 to 75 gal. per min. ..... $C = 11.5 + 0.65 \times G$.
For an ejector, capacities up to 10 gal. per min. .... $C = 0.72 + 0.338 \times G$.
Capacities from 10 to 125 gal. per min. ..... $C = 3.56 + 0.1345 \times G$.

TABLE LXXXIII. COST DATA FOR SINGLE-TUBE INJECTORS

Capacity, gal. per min.	Boiler hp.	Cost, dol.
1	8	2.70
1	6	4.50
1.3	11	4.80
1.3	8	4.00
2	15	3.25
2	19	5.40
3	22	5.00
3	22	6.00
3.5	30	4.50
4	34	7.50
4.3	32	7.50
6	45	7.50
7.5	65	7.20
8	64	12.00
8.3	65	13.50
10	80	11.25
12.7	120	9.90

Capacity, gal. per min.	Boiler hp.	Cost, dol.
13.3	106	16.50
13.3	100	13.75
23.3	181	22.50
23.3	180	18.75
23.3	180	22.50
40	320	33.00
40	320	27.50
40	320	37.50
60	480	45.00
70	600	60.00
75	600	60.00

TABLE LXXXIV. COST DATA FOR DOUBLE-TUBE INJECTORS

Capacity, gal. per min.	Boiler hp.	Steam pressure	Cost, dol.
1.3	11	..	4.80
2	15	80	6.00
2.3	19	..	5.40
3.7	25	80	7.50
4.3	34	..	7.50
7	50	80	12.00
8	64	..	12.00
12	95	80	16.50
21	165	80	22.50
37	295	80	33.00
40	320	..	33.00
58	460	80	45.00
60	4.80	..	45.00
60	500	80	52.50
66.7	600	80	60.00
75	600	..	60.00

TABLE LXXXV. COST DATA FOR RESTARTING INJECTORS

Capacity, gal. per min.	Boiler hp.	Lift, ft.	Steam pressure	Cost, dol.
0.5	4	3	75	3.90
1	8	3	75	4.20
1	6	..	..	5.40
1.5	12	3	75	4.80
1.5	10	..	..	6.30
2	20	3	75	5.40
3	20	..	..	7.95
4	45	3	75	7.50
6.4	45	..	..	11.85
8	80	3	75	12.00
10	90	..	..	17.70
13.3	135	3	75	16.50
22.5	175	..	..	28.50
23.3	235	3	75	22.50
37	300	..	..	42.00
40	380	3	75	33.00
57.5	950	..	..	54.00
60	550	3	75	45.00
75	750	3	75	60.00

TABLE LXXXVI. COST DATA FOR EJECTORS

Capacity, gal. per min.	Cost, dol.	Capacity, gal. per min.	Cost, dol.
1.3	1.35	37.5	9.00
2	1.80	62.5	11.25
3	2.03	79.1	15.75
4	2.25	83.3	14.63
5	2.40	83.3	15.00
10.8	4.50	108.3	18.00
12.5	4.50	113.3	23.80
13.3	4.50	125	20.35
23.3	7.88	153.3	32.60
29.1	7.85	250	21.00
33.3	7.50	750	52.50

TABLE LXXXVII. EFFECT OF INJECTOR TYPE ON COST

Gal. per min.	Cost of injector, dol.			
	Single-tube	Double-tube	Restarting	Ejector
20	$18	$20	$24	$6.50
40	34	36	37	9.00
60	50	52	50	11.75
80	65	68	64	14.50

INJECTORS

METROPOLITAN AUTOMATIC INJECTOR

Size, in.	Hp.	Net price
2	4– 6	$4.50
3	6– 8	4.80
3½	8– 15	5.40
4	15– 20	6.00
5	20– 30	7.50
6	30– 45	9.00
7	45– 65	12.00
8	65– 80	13.50
9	80–100	16.50
10	100–130	18.00
11	130–170	22.50
12	170–230	27.00
13	230–300	33.00
14	300–375	37.50

METROPOLITAN DOUBLE-TUBE INJECTOR

Size, in.	Hp.	Net price
2½	8– 15	$11.70
4¼	15– 20	13.00
5½	20– 30	16.50
6½	30– 45	19.50
7½	45– 65	26.00
7½	65– 80	29.30
9½	80–100	35.70
10½	100–130	39.00
11½	130–170	48.80
12½	170–230	58.50
13½	230–300	71.50
14½	300–375	81.20
15½	375–500	97.50
16½	500–650	130.00
17½	650–775	162.00
18½	775–950	195.00

Price of Pipe Covering. The following table gives the net price of sectional pipe covering, 85% magnesia.

Inside diam., in.	Weight, lb. per ft.	Net price per ft.
0½	0.75	$0.09
0¾	0.85	0.095
1	0.94	0.11
1¼	1.12	0.12
1½	1.40	0.13
2	1.50	0.14
2½	1.88	0.16
3	2.25	0.18
3½	2.45	0.20
4	2.80	0.24
4½	3.55	0.26
5	4.10	0.28
6	4.50	0.32
7	5.20	0.40
8	6.00	0.44
9	7.00	0.48
10	8.00	0.52
12	11.20	0.74

Asbestos Air-cell pipe covering costs about 35 to 40% less than 85% magnesia coverings listed above.

Labor Cost of Lagging Steam Pipe with standard magnesia pipe covering is given by Mr. R. K. Stockwell in Engineering and Mining Journal, Mar. 22, 1913. The work comprised the covering of 2,400 ft. of high pressure steam heating line running from the power house to the concentrator, and the steam and feed water lines of two 450-boiler-hp. reverberatory-furnace waste-heat boilers, at McGill, Nevada, in October, 1909. The men who did the work were pipe fitters rated at 50 ct. per hr., each with two helpers at 37.5 ct. per hr. The high pressure covering was 1.5 in. thick, held away from the pipe by bands of magnesia 1 in. thick, 18 in. apart. The covering for 10-in. and larger pipe came in keystone-shaped strips, and was placed on the bands, the cracks plastered with magnesia, mud and cement, the whole covered with canvas, clamped with brass bands 30 in. apart, and painted with tar and gasoline. The high pressure pipe covering for pipes 8 in. and less in diam. came in half cylinders 1.5 in. thick, and the low pressure pipe covering for pipes of less than 8-in. diam. in half cylinders 1 in. thick. The finish was the same as for the large high pressure pipes. The magnesia coverings for fittings, valves, etc., had to be sawed and fitted to the work by hand, which was slow and expensive. In the labor costs which follow all flanges are figured as part of flange unions.

Labor costs of applying magnesia covering to pipes and fittings were:

High pressure covering	Cost per lin. ft.
4-in. pipe	$ .17
8-in. pipe	.38
10-in pipe	.79
12-in. pipe	1.25
8-in. pipe bends	1.03

High pressure covering	Cost each
1.5-in. elbows	$1.30
8-in. elbows	3.30
10-in. elbows	3.58
12-in. elbows	4.90
4-in. expansion joints	2.60
10-in. expansion joints	5.63
12-in. expansion joints	6.15
1.5-in. flange unions	1.03
4-in. flange unions	1.19
8-in. flange unions	3.19
10-in. flange unions	3.40
12-in. flange unions	5.49
1.5-in. valve bodies	1.60
8-in valve bodies	3.28
10-in. valve bodies	3.60
12-in. valve bodies	4.90
8-in. valve bonnets	3.25
10-in. valve bonnets	3.60
12-in. valve bonnets	3.70

Low pressure covering	Cost per lin. ft.
2.5-in. pipe	$ .10
4-in. pipe	.12

	Cost each
2.5-in. flange unions	$1.15
2.5-in. tees	1.30
4-in. tees	1.75
2.5-in. elbows	1.30
2.5-in. valve bonnets	1.98

Average Cost of Steam and Water Piping, Valves and Separators. W. H. Weston, Engineering Magazine, January, 1912, has given the following table for compound condensing plants.

Hp.	Costs
400	$3,600
500	4,000
600	4.500
800	5,200
1,000	6,200
1,500	9,000
2,000	11,000
4,000	20,000

The Cost of Piping. The following is from a paper by E. Horton in the July, 1914, Bulletin of the A. I. M. E. The cost of piping at the Arizona Copper Company's New Smeltery, at Clifton, Arizona, was $122,389. The various items of cost are given herewith and include excavation, cost of material at Clifton and all labor of erection. The cost of engineering and superintendence amounts to 5.40% extra and the cost of indirect expense amounts to 7.53% extra.

Blast Pipe from Fans to Roasters in Roasting Plant. This pipe was made of No. 10 and No. 12 plate and varied in diam. from 18 ins. to 36 ins. The inlet pipe to each roaster was 18 ins. diam. Installation of this pipe included in the cost given herewith consisted of connecting up and riveting the pipe in place in the field only. This piping amounted to 240 ft. and cost of material, fabri-

cation and installation was: Labor, $1569.62; material, $656.62; total, $2,226.24. Cost per ft., $9.28.

Piping in Reverberatory Plant. Miscellaneous piping, boilers and reverberatory building; the sizes were various and amount of piping installed was not given. Costs were: Labor, $524.15; material, $1409.85; total, $1934.00.

Feed piping from heating plant to feed pumps: Excavating 1296 cu. yd. of trench from hot-water heating plant to boiler feed pumps through red clay filled with boulders, sand and gravel. The work was performed with picks and shovels and handled 300 ft. with wheel barrows and slips. Much of the dirt had to be handled 3 times in removing it from the trench; 200 ft. of the trench was cribbed and lagged 20 ft. high. Cost: Labor, $1039.91; material, $51.51; total, $1091.42. Cost per cu. yd., 84 cts.

In installing this pipe ordinary vitrified 15-in. sewer pipe cut in half was used for conduit. The first half was laid in the trench and the joints cemented, following by laying an 8-in. standard wrought-iron pipe. About this pipe an asbestos filler was packed, and after each section of conduit top was laid, the filler was stuffed in over the pipe to thoroughly cover it. The cost of labor was $386.25. Cost of supplies follows: 557 ft. of 15-in. J.-M. sectional conduit, $2273.47; 557 ft. of 8-in. wrought-iron pipe, $374.49; asbestos filler and miscellaneous, $109.83; total supplies, $2757.79. Total pipe work amounted to 557 ft. Total cost, $3144.04. Cost per ft. of pipe, $5.64. Total cost of feed piping from heating plant to feed pumps, including trenching, $4325.46. Total cost per ft., $7.60.

Feed piping from pumps to boilers: This represents pipe fittings, pipe covering, paint and labor in erecting, covering some of the pipe with insulation and painting all the pipe. The piping was about 1 steam and 2 electric feed pumps at the boilers. It also covered a hot-water line the length of the boiler building and a cold-water line of the same length. Each is connected to the boilers. The 2 main lines are 6 in. Connections to the boilers are 3 in. The hot-water lines are covered throughout. Labor cost was $1060.53. Materials cost: Standard pipe, $416.39; extra heavy fittings, $2408.89; pipe covering, $137.26; hangers and miscellaneous, $78.46; total material cost, $3041. Total amount of piping, 1093 ft. Total cost, $4101.53. Cost per foot of pipe, $3.75. Total cost of piping for reverberatory plant of 1200 ton capacity in 24 hrs., $10,370.99.

Piping in Converter Plant. Air pipe from power house: Excavating 331 cu. yd. of trench through sand, gravel and boulders with pick and shovel, and backfilling same, $224.06; Cost per cu. yd., 68 cts. The pipe ran from the power house to connect with all the converters, and was built to carry air under 12 lbs. pressure of No. 8 U. S. gage plate riveted, tested for 25-lb. pressure and painted with asphaltum paint. It was made in 30 ft. sections and fastened together with forge-steel flanges. Labor cost was $674.62. Material cost was: 400 ft. 24-in. pipe, 10-in. cast-iron nozzles, tees and ells, $1332.70; 22 ft. 10-in. pipe and two 10-in. flanges, $27.54; two 24-in. cast-iron gate valves, $138.55; miscellaneous, $127.85; total ma-

terials, $2941.89. Total cost, $2716.51. Total piping, 422 ft. at $6.43. Total cost of air pipe from power house, including excavating, $2940.57. Total cost per ft., $6.97.

Sewer System. Excavating 2967 ft. of trench and tunnel. Trenches varied from 18 to 60 ins. wide and 2 to 20 ft. deep through various kinds of soil. Costs were: Labor, $2122.84; material, $65.20; total, $2188.04. Cost per lin. ft., 74 cts. Concrete work amounting to 53.8 ft. of manholes, etc., was performed. The mix was 7 of sand and gravel to 1 of cement. This work cost: Labor, $168.18; material, $184.08; total, $352.26. Laying and cost of pipe, which consisted of 2967 ft. of vitrified sewer pipe, ranging from 6 to 15 ins. in diam. and laid at an average depth of 4 ft. below surface. Cost, $778.83 for labor and $1224.72 for supplies; total, $2003.55. Cost per ft. of pipe, 68 cts. Total cost of sewer pipe, including excavation, $4543.85. Total cost per ft., $1.53.

Water Pipe Line. Excavating 4253 ft. of trench through various kinds of ground from 8 to 15 ft. in depth. Labor, $868.11. Cost per ft., 20 cts. Concrete work, 2.3 cu. yd., to anchor 6-in. line at foot of hill. Labor, $17.37; material, $17.86; total $35.23. Cost per cu. yd., $15.32. Pipes and laying; all water lines about smelter consist of 2052 ft. of 6-in. pipe, 1058 ft. of 4-in. pipe, 200 ft. of 2.5-in. pipe, 268 ft. of 2-in. pipe, 115 ft. of 1.5-in. pipe and 50 ft. of 1-in. pipe; total, 4253 ft. of pipe, and all necessary fittings, valves and fire hydrants. Cost of labor, $2863.32; material, $2062.07; total, $4925.39. Cost per ft. of pipe, $1.16. A 6-in. pipe line from Clifton, distance 8988 ft.; cost, including excavation, laying, material, painting and back-filling, labor, $1474.71; material, $6914.95; total, $8389.66. Cost per ft. of pipe, 93 cts. Total cost of all water pipes, $14,218.39. Total cost per ft., $1.08.

Air Line. Excavating trenches amounting to 401 cu. yd. through various kinds of soil and ranging from 18 ins. to 6 ft. in depth and 1 to 3 ft. in width. Cost, including back-filling: labor, $267.50. Cost per cu. yd., 67 cts. The air lines together were 2316 ft. long and were made up of the following quantities of pipe: 526 ft. of 1-in. pipe, 36 ft. of 1.25-in. pipe, 80 ft. of 1.5-in., 656 ft. of 2-in., 838 ft. of 3-in. and 180 ft. of 4-in. pipe. Cost was as follows: Labor, $432.37; material, $623.08; total, $1055.45. Cost per ft., 46 cts. Total cost of air line, including excavation, $1322.95. Cost per ft., 57 cts.

Steam-Heating System. Excavating 225 cu. yds. of shallow trench through red clay and backfilling. Labor cost, $166.36. Cost per cu. yd., 73 cts. This pipe was covered with double standard magnesia covering, 260 ft. of 2-in., and 236 ft. of 2.5-in. steam pipe were laid in a 2-in. lumber box. Total pipe, 496 ft. Cost: Labor, $240.78; material, $305.37; total, $546.15. Cost per ft. of pipe, $1.10. Total cost of steam-heating pipe system, $712.51. Cost per ft. of pipe, $1.43.

Power-house piping. Air pipes or ducts for turbines. This pipe was made in the shop of No. 16 steel with 2.5 by 2.5 by .25 angles. Total length, 103 ft. Cost of labor, $547.68; materials, $200.75; total, $748.43. Cost per ft., $7.27.

In erecting this pipe, cloth insertion packing, rivets, hangers, anchors, etc., were used. Cost of labor, $232.57; material, $64.24; total, $296.81. Cost per ft., $2.88. Total cost of air ducts for turbines, $1045.24. Cost per ft., $10.15.

Erecting compressor: All piping, except steam, used in erecting Ingersoll-Rand two-stage compressor. Cost of labor, $298.46; material, $160.65; total, $459.11.

Steam pipe for north and south mains: Excavating 279 cu. yd. for numerous piers done with pick and shovel and cast to one side. Labor cost, $240.65. Cost per cu. yd., 89 cts.

Foundations: These are concrete piers which support the long structural steam-pipe supports. Part of the concrete was mixed by machine and part by hand in proportions of 6 sand and gravel to 1 cement. There were 194.5 cu. yds. and about 50% of the vertical surface was formed. Cost of labor, $578.24; material, $945.97; total, $1524.21. Cost per cu. yd., $7.84.

Steel support structures for these mains consist of 11.8 tons of corrugated iron and 75.01 tons of structural steel. Cost, including labor, $7894.58. Cost per ton, $88.64.

Hangers and anchors used for steam piping between boilers and the machines in the power house were made of .75-in. rods and .5 by 2.5-in. iron. Cost of labor, $1030.68; materials, $337.26; total, $1367.94. Total, 153 rods at $8.94.

Cost and erection of pipe: the pipes run from the boilers to the power house in duplicate, making a complete loop about 1120 ft. around. The main lines are 10 ins., branches from boilers 8 ins., and all branches to engines of suitable sizes ranging from 4 to 8 ins. The line is required to stand 180 lbs. pressure with 100 deg. F. superheat. All joints are Van Stone, all valves and fittings are of cast steel. Corrugated bronze gaskets were used. The 10-in. lines are fitted with six 10-in. Labor cost was $2286.31. The following gives some details of materials and cost:

6 10-in. Harter expansion joints	$ 1,684.77
1 6-in. cast-iron separator	126.55
2 10-in. cast-steel vertical separators	843.47
1 10-in. cast-steel horizontal separator	372.48
2 6-in. separators and receivers	591.77
1 5-in. cast-steel separator and receiver	261.40
3 4-in. cast-steel separators and receivers	687.43
2 4-in. cast-steel separators and receivers	476.28
Corrugated bronze gaskets	251.93
10 8-in. Lagonda valves	1,315.52
12 10-in. gate valves	2,079.00
2 34-in. and 1 33-in. Crane tilt traps	143.69
Best Mfg. Co. pipe and fittings	8,738.89
Extra pipe and fittings	526.18
Miscellaneous	522.89
Total cost of materials	$18,622.25

Total cost of labor and materials, $20,908.56. Total pipe work, 3401 ft. at $6.15 per ft. The steam pipes and all fittings were covered with 85% magnesia blocks of double standard thickness, wrapped with 6 oz. duck. All the lines were then painted with two

coats. Cost, $6079.94. Cost per ft., $1.79. Total cost of steam lines, north and south mains, $37,824.88. Cost per ft., $11.10.

Exhaust pipe: Some of the piping used was cast-iron, designed for a vacuum of 14 lbs. per sq. in. The rest of the pipe used was lap-welded wrought steel and cast-iron fittings. The installation covers the 3 20-in. atmospheric exhausts from the turbines, as well as the exhausts from the blowers, compressors, exciters, engines and circulating pump engines, to the jet condenser. It covers likewise the connections between the exhaust of the dry-vacuum pumps, exciters, engines, surface condenser, circulating pumps and heater house. The pipe ranges from 3-in. to 42-in. There were 1541 ft. of pipe. The labor cost for installation was $1745.71. The supply cost was $8715.66, made up as follows: Wainwright turbine expansion joints, $656.70; 3 20-in. atmospheric relief valves, $804.50; 3 42-in. low-pressure flanged base elbows, $1428.61; 3 special 8-in. emergency-stop valves, $234.36; 1 14-in. automatic atmospheric-exhaust relief valve, $123.27; pipe and fittings, $4585.74; miscellaneous, $882.48. Total cost of labor and material, $10,461.37. Cost per ft., $6.79.

All exhaust pipe was given one coat of green silica graphite paint. Cost of labor, $85.05; material, $51.19; total, $136.24. Cost per ft., 9 cts.

The exhaust pipes from the engines in the power house to the heater house were all covered with 85% magnesia single standard thickness, wrapped in 6-oz. duck. Where the magnesia is exposed to the weather, it is wrapped with No. 28 galvanized iron. Total pipe covered, 746 ft. Labor cost, $318.25; material, $830.56; total cost, $1148.81. Cost per ft., $1.54.

Other costs, including air pipe and erection, painting, exhaust-pipe foundations, supporting structure excavation. Labor cost was $675.93; material, $733.56; total, $1409.49.

Water pipe about power house: Excavating a trench about 3 ft. deep through red clay and boulders for a 16-in. wood stave pipe, 2406 cu. yd. of earth removed. Cost, including back-filling: Labor, $1485.10; material, $0.24; total, $1485.34. Cost per cu. yd., 62 cts.

The following covers all the water pipe about the power house, the 30-in. cast-iron suction line from the cooling tower to the pumps; the 20-in. wooden lines from the pumps to the equalizing tank; the 16-in. wooden lines from the jet condenser to the cooling tower, and the 12-in. cast-iron lines from the circulating pumps to the jet condenser; the 8-in. line from the condenser to the condensed water pump house; the 6-in. line from the condensed pump house to heater house, etc. Labor cost for erection was $3747.79. The following gives details of materials and their cost:

1998.7 ft. 4-in. machine banded redwood pipe with collars (not used at new smelter)	$ 397.74
354.6 ft. 20-in. machine banded redwood pipe with collars	365.24
1104.2 ft. 16-in. machine banded redwood pipe with collars	861.28
22 flange couplings	590.00
Freight on the above items	632.00
2 12-in. check valves	97.00
4 12-in. gate valves	172.00

3 20-in. gate valves	283.50
Freight on above items	176.38
3 20-in. flanged iron body, bronze-mounted double gate valves	403.49
5 No. 20 gage copper plates	36.28
2 cast-iron bell-and-flange fittings, 6 bell bends	81.11
Freight and patterns on above	78.00
220 lbs. cloth insertion packing	91.50
Best Mfg. Co. pipe	9,668.92
Pipe, fittings, miscellaneous material	2,503.44
Total cost of material	$16,437.88

Total cost of labor and materials, $20,185.67.

All this pipe above ground was painted at a cost of: Labor, $230.59; material, $25.54; total, $256.13.

Sewer pipe for feed water heating plant: Excavating and backfilling a trench about 3 ft. deep through red clay and boulders, 266 cu. yd. Labor cost, at 59 cts. cu. yd., $157.19.

Sewer pipe and laying 100 ft. of 24-in. vitrified pipe. Cost of labor, $71.88; material, $203; total, $274.88. Cost per ft., $2.75. Total cost of sewer, $432.07. Total cost per ft., $4.32. Total cost of power house-piping (except possibly a few small items connected with pumps, etc.), $74,844.35.

Oil-Supply Sump and Pump House. Inlet piping, oil sump: The following is for installing and cost of this pipe between the unloading tracks and oil sump: Labor, $44.77; 6 10-in. wrought pipe 18 ft. long, $85.54; 6 10-in. cast-iron cells, $38.64; miscellaneous, $2.37; total, $171.32. 108 ft. of piping at $1.59.

Oil piping: Excavating trenches from 500,000 gal. oil tank to small 163-bbl. tanks. Trenches were 2 ft. wide and about 3 ft. deep. Total earth removed, 1150 cu. yd. Cost of labor, $990.73; material, $1.39; total, $992.12. Cost per cu. yd., 86 cts.

Pipe and laying: there were 1888 ft. of pipe, consisting of 172 ft. of 12-in. wrought-iron pipe, 270 ft. of 16-in., 850 ft. of 8-in. and 596 ft. of 2.5-in. wrought-iron pipe. A 16-in. line runs from the oil sump to the pump house, also from pump house to storage tanks. The 8-in. line runs from the pump house to the 163-bbl. tanks. The 2.5-in. line runs from the Wilgus oil pumps to each of the reverberatories. Cost of labor, $3156.14; material, $5654.50; total, $8810.64. Cost per ft. of pipe, $4.67.

Heating installation for oil piping: a 2.5-in. steam line is tapped off the steam line at power house and runs underground through a conduit and is packed in asbestos fiber. At the other end, the pipe connects with a cast-iron oil heater. Labor cost for installing was, $167.37. Materials cost $1068.04 and consisted of a cast-iron heater, $303.82; No. 33 Crane tilt trap, $35.91; 280 ft. 8-in. conduit, $547.49; asbestos, $29; 2.5-in. pipe and fittings, $151.82. Total cost of labor and material, $1235.41. Total piping, 360 ft. at $3.43 per ft. Total cost of piping at smelter as given in details of cost, $11,389.34.

Pipe Line Leakage. Trans. A. I. M. E. Vol. 30. At No. 6 Colliery, Glen Lyon, Pa., the main pipe line is 4380 ft. long, of 5 ins. diam., and has a cubic capacity of 608 cu. ft., with a branch line

3100 ft. long, of 3 ins. diam., and a capacity of 159 cu. ft. The gauge pressure is 600 lbs., which gives an equivalent capacity of 32,500 cu. ft. of free air. The loss per hr. from leaks is 974 cu. ft. of free air or 4.18% of the total air compressed.

Average Cost of Boiler Feed Pumps. W. H. Weston has given the following data in The Engineering Magazine, Jan., 1912, for compound condensing plants.

Hp. of plant	Cost of Feed pumps, completely installed
400	$160
500	175
600	190
800	220
1,000	250
1,500	325
2,000	380
4,000	700

Cost of Pumps. The following equations, taken from Bulletin No. 2, Kansas State Agricultural College, Boiler Room Economics, by A. A. Potter and S. L. Simmering, give the cost, C, in dollars for various types of reciprocating pumps in terms of capacity, G, expressed in gallons per hour.

Boiler feed pumps, piston pattern, single cylinder:

For capacities of 6000 gals. per hr. or less, $C = 17.8 + 0.0259 \times G$; 6000 to 27,000 gals. per hr., $C = 107 + 0.011 \times G$.

For a duplex pump of the same type, and capacities from 2,500 to 30,000 gals. per hr., $C = 58.5 + 0.0115 \times G$.

Boiler feed pumps, single cylinder, outside-packed plunger type: $C = 0.034 \times G - 20$. For a duplex pump of the same type, $C = 0.0421 \times G - 221$.

Geared power pumps, single cylinder: $C = 90 + 0.0316 \times G$.

Geared power pumps, single acting triplex type: $C = 56 + 0.0388 \times G$. For a double acting pump of the same type, $C = 195 + 0.0148 \times G$.

Rotary force pumps: $C = 8 + 0.0117 \times G$.

Wet vacuum pumps: For capacities up to 10,000 gals. per hr., $C = 18 + 0.0143 \times G$. From 10,000 to 50,000 gals. per hr., $C = 14 + 0.00863 \times G$.

The following equations give the cost, C, in dollars for centrifugal pumps when the capacities are expressed in gallons per minute, G.

Centrifugal pumps, horizontal, low pressure, single stage type: $C = 52 + 0.0552 \times G$.

Centrifugal pumps, horizontal, high pressure, single stage type: For capacities up to 5,000 gals. per min., $C = 61 + 0.0868 \times G$. From 5,000 to 20,000 gals. per min., $C = 210 + 0.0567 \times G$.

Centrifugal pumps, horizontal, high pressure, multi-stage type: $C = 117 + 0.233 \times G$.

Centrifugal pumps, vertical, low pressure, single-stage type: $C = 60 + 0.0557 \times G$.

Centrifugal pumps, vertical, high pressure, single-stage type: $C = 50 + 0.0865 \times G$.

Centrifugal pumps, vertical, high pressure, multi-stage type: $C = 125.7 + 0.27 \times G$.

The cost of a duplex-geared pump is stated by different manufacturers as twice that of a single-cylinder pump plus 10%.

For further data on pumps and costs thereof, see Chapter XVII.

Cost of Water Purification Plants. We have abstracted the following from Bulletin No. 2, Kansas State Agricultural College, Boiler Room Economics, by A. A. Potter and S. L. Simmering. Table LXXXVIII gives the capacities of water-purification plants in gallons per hour, the cost of equipment and also the cost of erection. It is evident that the cost of erection rises much more rapidly for increased capacities above 7000 gals. per hr. than from 0 to 7000 gals. per hr., whereas the cost of the equipment rises uniformly for the total range of capacities quoted. From the table the following equations were derived, giving the cost, C, in dollars expressed in terms of the capacity in thousands of gallons, G, per hour.

TABLE LXXXVIII. COST DATA FOR WATER-PURIFICATION PLANTS

Capacity, gal. per hr.	Cost, dol.	Cost of erection, dol.
1,000	$900	$225
1,000	1,000	150
1,500	1,150	235
2,000	1,300	245
2,000	1,500	200
3,000	1,500	250
3,000	1,900	220
4,000	1,750	250
5,000	2,000	260
5,000	2,300	500
6,000	2,250	275
7,000	2,600	300
8,000	2,600	500
10,000	3,000	600
10,000	3,300	700
12,000	3,500	800
15,000	4,000	875
15,000	4,000	900
20,000	5,000	1,000
20,000	4,400	1,100

OIL SEPARATORS

STANDARD HORIZONTAL TYPE

Size, ins.	Weight, lbs.	Net price
2	80	$8.00
3	150	15.40
4	200	17.60
5	230	20.00
6	260	24.00
8	450	36.00
10	580	46.00
12	725	60.00
14	875	76.00
16	1,200	102.00

VERTICAL RECEIVER TYPE

Size, ins.	Weight, lbs.	Net price
2	140	$13.60
3	225	17.60
4	325	26.00
5	500	37.60
6	625	45.60
8	850	62.00

RECEIVER TYPE STEAM SEPARATORS

VERTICAL CLASS

Size, ins.	Weight, lbs.	Net price
2	300	$36.00
3	425	47.20
4	650	67.50
5	850	85.50
6	1,200	112.50

HORIZONTAL CLASS

Size, ins.	Weight, lbs.	Net price
2	475	$49.50
3	650	63.00
4	825	76.50
5	1,000	90.00
6	1,300	112.50

The above separators are used for 200 lb. working pressure.

STANDARD STEAM SEPARATORS

VERTICAL CLASS

Size, ins.	Weight, lbs.	Net price
2	200	$18.40
3	300	25.60
4	425	36.80
5	650	50.00
6	825	61.50
7	1,125	69.50
8	1,350	88.00

HORIZONTAL CLASS

Size, ins.	Weight, lbs.	Net price
2	100	$12.00
3	175	14.40
4	250	20.00
5	350	28.00
6	450	32.00
8	775	52.00

The above separators are used for 150 lb. working pressure.

Cost of equipment, $C = 1000 + 0.2 \times G$.

Cost of erection, $C = 160 + 0.02 \times G$ for capacities from 0 to 7000 gals. per hr., and $C = 211 + 0.0444 \times G$ for capacities from 8,000 to 20,000 gals. per hr.

Operation of Mechanical Stokers. R. J. S. Pigott gave the following data in the Proc. Am. Elec. Ry. Assn., 1914, abstracted by Lefax.

Mechanical stokers are practically limited to the firing of bituminous coal. Anthracite fuel has been handled successfully only with mechanical shovelers, which require almost as much attention as hand firing. Lignite has been generally unsuccessful on stokers up to the present time. The principal requirements of a stoker are to coke the green coal, mix air with the volatile matter where it can be ignited, burn the fixed carbon, dispose of the ash and clinker, and prevent sifting and clinker adherence to the brickwork and stoker parts.

In all overhead stokers the coal is fed in at the top and allowed to coke as it is gradually forced downward by gravity and rocking of the bars. As the green coal packs closely, air must be supplied through the lower part of the grate or through the openings in the arch. The length of flame for a semi-bituminous coal containing 17 to 25% volatile matter is over 30 ft. with these stokers. The distance from the grates to the tubes varies from 5 ft. to 9 ft. Accumulation of clinker must be prevented by slicing and periodic dumping. Too frequent dumping will prevent the complete combustion of carbon in the clinker, while the other extreme will cause the clinker to become large and hard to dislodge; 5 to 8% of the fuel will sift through overfeed grates, depending on the amount of air space and the condition of the grates. At the present time it is considered good practice to provide a stoker which is capable of operating the boiler at 200% of its rating continuously.

On chain grates coking occurs at the entrance to the stokers, but as the coking arch is much longer than for slope grates, the air and volatile matter are mixed more effectively and less loss due to incomplete combustion results. Clinker troubles are reduced as the grates are entirely cleared of ash and clinker and cooled by returning on the under side once every revolution. Chain grates weigh more per b.h.p. than other types, sometimes over twice as much as slope or underfeed grates. For instance, a chain grate stoker for a 600 h.p. boiler with a furnace width of 12 ft. 6 ins. weighs from 60,000 to 80,000 lbs., as compared with 30,000 lbs. for an inclined stoker, either over or underfed. Having larger areas than other overfeed grates, however, chain grates can be forced much higher if the proper quality of coal suited to the stoker is used. With low ash coals at high rates of driving, the grates become overheated. Chain grates at all ratings are suitable for high volatile (30–40%) and high ash (10–20%) coals.

Underfeed stokers have the following principal advantages: The tuyeres are covered with green or only partly coked coal so the grates are not liable to be burned; practically the entire furnace area is utilized to distill volatile matter; all of the air supplied to the furnace is immediately and intimately mixed with the volatile matter while it is still in the coal bed; the combustible gases pass through the hottest zone of the fire before reaching the furnace, and no arches are required. These stokers necessarily operate with forced draft as the air openings are restricted and the fuel bed is deep, from 1 to 4 ft. As no arches are required, considerable expense is eliminated in repairing brick-work. Underfeed stokers

TABLE LXXXIX. COST DATA FOR STOKERS

Type of stoker	Step and slope overfeed	V overfeed	Chain overfeed	Gravity underfeed	Horizontal retort underfeed
Average price per rated boiler-h.p.	$3.60	$3.60	$3.50 to $6.55	$5.65	$4.44
Normal forcing ability in % of rating	190	175	260	300–350	300
Price per maximum h.p. developable	$1.90	$2.06	$2.52	$1.88 to $1.62	$1.48
Maintenance per ton coal fired, ct.	10–12	11–14	6–10	2.5–4	4–6
Attendance in man-hours per active hour	0.45	.45–.50	.20–.30	.08–.10	30–.40
Lb. coal per sq. ft. grate surface (maximum)	35–38	35–42	45–48	60–75	50–65

have great forcing capacity; 300% of rating can be maintained continuously at 60 to 65 lbs. of coal per sq. ft. of grate.

The efficiencies of modern stoker installations are shown by the curves in Fig. 86. These indicate boiler efficiency alone and do not allow for steam consumed by auxiliaries such as blowers, stokers and boiler-feed pumps. In general the best efficiency is shown when the boiler is operated at less than 100% rating. Curves *A* and *B* indicate an exception to this statement. As the net output of steam for a given coal input is affected relatively more at low loads than at high loads by the steam consumed by the auxiliaries, it is advisable to operate the boilers at about 25% higher than their most efficient rating as shown by the curves to obtain the best plant efficiency. The principal factor influencing the load to be carried by a boiler is the relation between fixed and operating costs.

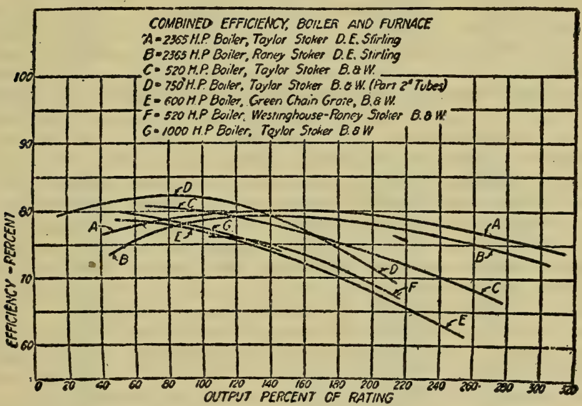


Fig. 86. Efficiencies of modern stoker installations.

Cost of Maintaining Four Stokers and Furnaces for Six Years. The data in the accompanying table from Electrical World, Dec. 16, 1916, show what it has cost a Middle West central station exclusive of labor charges to maintain four 10-ft. by 10-ft. chain-grate stokers and their furnaces during the 6 years they have been in service. It will be noted that the total expense for material has been $2,735.75 or an average of $114.99 per stoker per year. Of this amount $2,354.87 has been spent for tile and fireclay, while $400.88 has been spent for stoker parts, and steel and iron parts of arches and feed gates. The cost per stoker per year for tile and fireclay was $97.29, and the cost per stoker per year for all castings and steel parts was $16.70. In other words, the cost of the tile and fireclay represented 85% of the total material maintenance cost.

TABLE XCA. COST OF STOKER AND FURNACE REPAIRS FOR SIX YEARS

	Stoker parts and iron parts of arch and feed gate	Tile and fireclay	Total
1910	$60.00	......	$60.00
1911	14.00	$142.25	156.25
1912	61.12	823.17	884.29
1913	40.50	67.50	101.00
1914	3.00	217.00	220.00
1915	33.25	190.25	223.50
1916	189.01	894.70	1,083.71
	$400.88	$2,334.87	$2,735.75
Total per stoker per year	$16.70	$97.29	$114.99

A more detailed analysis of the cost of maintaining metal parts shows that the cost of replacing operating parts of the four stokers was but $8.77 per stoker per year, which is a very small percentage of $1800, the present cost of such a unit without firebrick. Further study of data concerning the cost of the tile also shows that in 1912, when the maintenance cost was high, one complete 9.5-ft. by 6.5-ft. arch, and 50 large 4-in. by 12-in. by 24-in. bridge wall tile were purchased at a total cost of $498.22, which helped appreciably to increase the total for the year.

Cost of Stokers. The following data are from Bulletin No. 2, Kansas State Agricultural College, Boiler Room Economics, by A. A. Potter and S. L Simmering. It is difficult to express by a single equation the cost of a stoker equipment, as the numbei of stokers required, the draft necessary, the kind of fuel and other conditions all tend to cause a variation in price. For example, the cost of an underfeed stoker of a certain make is $1055 for 1 125-h p. boiler, $1793 for 2 125-h.p. boilers and $6,300 for 8 boilers of the same capacity. One manufacturer of front-feed stokers quoted $975 for a single boiler equipment and $1680 for a 2-boiler equipment. Tables XC-XCII give the costs of various types of stokers. The following equations apply very nearly to equipments for not more than 4 boilers. The cost, C, in dollars is expressed in terms of the boiler horsepower, h.p. served by the stokers.

Chain-grate stokers: for boiler capacity of 300 h.p. or less, $C = 86 + 4.28 \times \text{h.p.}$; for capacities from 300 h.p. to 500 h.p. $C = 434 + 3.1 \times \text{h.p.}$

Mechanical underfeed stokers: $C = 379 + 2.785 \times \text{h.p.}$

Mechanical front feed stokers: $C = 312 + 3.015 \times \text{h.p.}$

TABLE XC. COST DATA FOR MECHANICAL CHAIN GRATE STOKERS

Boiler h.p.	Cost, dollars Total	Per h.p.
125	$750	$6.00
200	1,150	5.75
300	1,350	4.50

Boiler h.p.	Total	Per h.p.
300	1,380	4.60
400	1,600	4.00
400	1,760	4.40
500	1,800	3.60
Large sizes		4.00

TABLE XCI. COST DATA FOR MECHANICAL UNDERFEED STOKERS

Boiler h.p.	Cost, dollars	
	Total	Per h.p.
125	$850	$6.80
125	1,115	8.92
150	1,055	7.03
150	897	5.97
200	765	3.82
300	1,075	3.58
300	1,250	4.17
350	1,669	4.76
400	1,350	3.37
500	1,600	3.20
600	1,800	3.00
600	2,300	3.83

TABLE XCII. COST DATA FOR MECHANICAL FRONT FEED STOKERS

Boiler h.p.	Cost, dollars	
	Total	Per h.p.
100	$550	$5.50
125	825	6.60
137	665	4.85
150	690	4.60
175	750	4.28
200	925	4.63
250	940	3.61
275	965	3.50
300	1,140	3.80
330	1,225	3.71
375	1,375	3.67
400	1,500	3.75
450	1,700	3.78
500	1,880	3.76
550	2,000	3.63
610	2,100	3.44
660	2,300	3.48

Mechanical Stokers, Installed. W. H. Weston, Engineering Magazine, January, 1912, has given the following table, the horsepower being figured on compound condensing basis.

H.p.	Cost
800	$2,600
1,000	3,000
1,500	4,300
2,000	5,500
4,000	10,000

Cost of Superheaters. The following data are from Bulletin No. 2, Kansas State Agricultural College, Boiler Room Economics, by

A. A. Potter and S. L. Simmering. The prices in Table XCIII apply to attached or built-in super-heaters. These prices vary with the general shape, size and construction, as well as with the degree of superheat to be maintained. This latter variation is shown by the equations for 100, 200 and 300 degs. of superheat.

C, in dollars, is expressed in terms of the boiler horsepower, h.p.

For 100 deg. of superheat:	$C = 165 + 2.578 \times hp.$
" 200 " " "	$C = 52 + 3.466 \times hp.$
" 300 " " "	$C = 40 + 4.28 \times hp.$

TABLE XCIII. COST DATA FOR ATTACHED OR BUILT-IN SUPERHEATERS

Boiler h.p.	Total	Cost, dollars Per b h.p	Erection
	100 deg. superheat		
200	$750	$3.75	
250	700	3.50	$75
300	975	3.25	
400	1,200	3.00	
500	1,880	3.76	
500	1,380	2.76	145
750	2,025	2.70	225
	200 deg. superheat		
250	915	3 66	85
500	1,800	3.60	190
750	2,650	3 53	275
	300 deg. superheat		
250	1,110	4.44	100
500	2,220	4.40	200
750	3,250	4.33	300

Steam Turbines. A. A. Potter, Power, Dec. 30, 1913, gives the following formulæ of cost in Table XCIV.

Dimensions, Weights and Costs of Steam Turbines. The following, taken from Power, June 1, 1915, is by A. A. Potter and S. L. Simmering, Kansas State Agricultural College. Tables XCV and XCVI were compiled from data supplied by manufacturers and should prove of value in connection with preliminary estimates. The dimensions, weights and cost data are for condensing units and include the turbines and alternating-current generators.

The values in Table XCVII were plotted and the following equations were deduced, giving the cost in dollars (C) of the turbine and generator, in terms of the capacity in kilowatts.

Impulse types $C = 5040 + 9.2$ *kws. (Dollars)*
Reaction types $C = 7400 + 8.26$ *kws. (Dollars)*

TABLE XCIV. COST OF STEAM TURBINES

Type	Capacity	Equation of cost, dollars
Reaction type: turbine and generator	500 to 5,000 kw.	3,335 + 13.33 × kw.
" " " " "	5,000 to 10,000 kw.	17,500 + 10.5 × kw.
Impulse type: turbine alone	Up to 50 h.p.	171.5 + 10.7 × h.p.
" " " "	50 to 400 h.p.	10.74 × h.p. — 54
Turbine and generator	Up to 40 kw.	304.2 + 36.78 × kw.
" " "	25 to 350 kw.	30.4 × kws. — 100
" " "	1,000 to 10,000 kws.	8,106 + 11.34 × kw.

TABLE XCV. DIMENSIONS AND WEIGHTS OF CONDENSING STEAM TURBINES, INCLUDING GENERATORS

Size, kw.	Impulse type							Reaction type						
	Length ft.	Length in.	Width ft.	Width in.	Height ft.	Height in.	Weight lb.	Length ft.	Length in.	Width ft.	Width in.	Height ft.	Height in.	Weight lb.
300	15	10	5	0	5	4	18,500	16	0	6	0	..	..	24,000
300								20	0	6	0	5	10	37,900
500								18	0	6	0	..	..	30,000
500	16	1	7	3	6	6	34,800	20	9	6	0	5	10	42,600
1,000								24	0	6	0	..	..	60,000
1,000	16	0	6	10	7	6	45,000	18	4	6	9	6	8	52,250
2,000	20	6	9	0	7	9	75,000	25	6	9	4	7	9	105,000
2,000								26	0	7	0	..	..	90,000
5,000	25	1	10	7	9	8	175,000	34	9	11	5	9	1	236,000
5,000								34	0	8	0	..	..	190,000
10,000	32	5	12	9	12	0	310,000	45	0	10	0	..	..	320,000

TABLE XCVI. COST OF CONDENSING STEAM TURBINES AND GENERATORS

Size, kw.	Impulse type Rev. per min.	Impulse type Cost	Reaction type Rev. per min.	Reaction type Cost
300	3,600	$8,000	3,600	$7,650
500	3,600	9,600	3,600	9,550
1,000	3,600	14,000	3,600	13,750
2,000	3,600	23,000	3,600	22,800
5,000	1,800	55,000	3,600	48,700
10,000	1,800	95,000	1,800	90,000

Prices of Steam Valves. The following were the net prices of valves before the war.

FISHER REDUCING VALVE

SCREWED CONNECTIONS

Size, in.	Net prices Angle pattern	Net prices Globe pattern
1	$21	$23
1¼	25	26
1½	30	32
2	35	37
2½	40	42
3	49	51

FLANGED CONNECTIONS

Size, in.	Net prices Angle pattern	Net prices Globe pattern
2	$35	$38
2½	42	45
3	52	56
3½	61	63
4	70	77
5	88	95
6	105	105
8	160	160

AUTOMATIC EXHAUST RELIEF VALVE

Size, in.	Approx. weight, lb.	Net price
2	50	$14.00
3	75	16.50
4	100	21.00
5	125	25.00
6	175	27.50
7	250	35.00
8	300	38.00
10	350	50.00

SAFETY VALVES

Size, in.	Diam. of flange, in.	Net price
2	7	$15.00
2½	7	20.00
3	9	22.00
3½	10	32.00
4	10	35.00
4½	12	40.00
5	12	42.50
5½	14	62.50
6	14	62.50

The above safety valves are for large stationary and portable boilers.

POP SAFETY VALVES

Size, in.	Net price Without cap or lever	With cap
1¾	$2.25	$2.50
1	3.25	3.50
1¼	4.25	4.50
1½	5.00	5.25
2	10.00	10.25
2½	16.00	16.50
3	20.00	20.50

For small stationary and portable boilers

SQUIRES IMPROVED STEAM TRAP

FITTED WITH REGULAR VALVE AND SEAT

Size pipe connections, in.	Capacity sq. ft. of radiation	Capacity Lb. of water per hr.	Net price
½	1,300	400	$15
¾	2,000	600	17
1	2,800	850	21
1¼	5,200	1,600	26
1½	8,100	2,500	38
2	12,900	4,000	53
2½	32,700	10,100	75

FITTED WITH UNLIMITED PRESSURE VALVE MECHANISM

Size pipe connections, in.	Capacity Lb. of water per hr.	Net price
1	2,700	$25
1¼	3,800	30
1½	5,500	45
2	10,000	63
2½	20,000	90

CHAPTER VIII

INTERNAL COMBUSTION ENGINES AND GAS PRODUCERS

Principal Economic Factors of Gas Power. These are: 1, the nature of available fuel; 2, the cost of installation; 3, the operating labor, water, oil and waste, etc.

Fuel differs in very great degree according to locality from which it is taken. Natural gas, containing a small percentage of highly inflammable constituents, mostly hydrogen, is generally clean, pos-

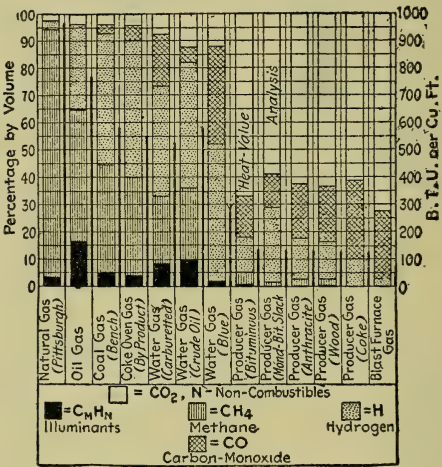


Fig. 1. Composition and heat value of fuel gases. (After Edwin D. Dreyfus, Power.)

sesses high heat values, and is obtained mostly in Western Pennsylvania, New York, West Virginia, Ohio, Kentucky, Kansas and Louisiana.

The gases obtained as distillate from oil refineries and from by-product coke and blast furnaces are available wherever such industrial plants exist, but on account of the impurities ordinarily encountered, such as ore dust, oily papers, lamp black, sulphuric compounds, it must be cleaned before delivery to the engine.

Illuminating gas is available in nearly all large cities and contains a high percentage of hydrogen, is of high heat value and generally is fairly clean. It is subject to the objections of rather high cost and its liability to pre-ignition. Gas made from coal or crude oil possesses the same limitations as illuminating gas, and water gas is even less satisfactory on account of its still lower heat value.

Producer gas is available wherever there is a supply of anthracite or bituminous coal, and presents the proper factor for comparing the operating costs of this type of equipment with those of the steam engine.

Thermal Efficiency is high in gas engines of all sizes, whereas it is not high in a steam engine except for the very large sizes. Fig. 2 gives the heat economy of turbines and gas engines ranging from 500 to 10,000 kw. units, together with a typical gas-engine curve applying to all sizes.

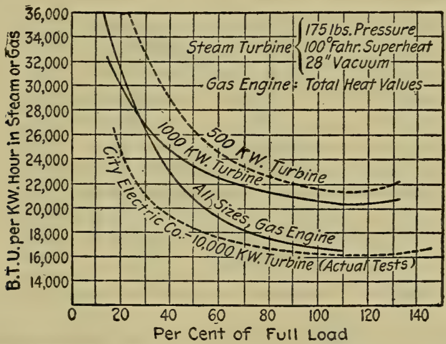


Fig. 2. Heat economy of turbines and gas engines.

Cost of Installation. Edwin D. Dreyfus, from whose excellent paper in Power for January 31, 1911, we have taken three illustrations under this caption, places the composite cost of the gas plant about 30% higher than that of a high grade steam plant because of the larger quantity of metal in the gas engine that must withstand higher combustion pressures and temperatures up to 3,000 degs. F., while a steam turbine undergoes pressures of 200 lbs. per sq. in. and under and temperatures not more than 500 degs. F. Another reason for the extra weight of the gas engine is that a turbine, for example, can operate at much higher speeds than could possibly be the case with gas engines. The element of metal, therefore, produces more power per unit of its weight.

Labor. This will not vary materially in small gas and steam plants and in large plants it may differ in favor of the steam turbine, but it will not differ much between a large reciprocating steam engine and a gas engine of the same power.

Fixed Charges. In Fig. 3 Mr. Dreyfus assumes 11% of the first cost as the proper fixed charges for both the gas and the steam plants. He considers that the real difference in obsolescence between the two types of plant is more or less intangible, and he has therefore ignored it in order to avoid complication.

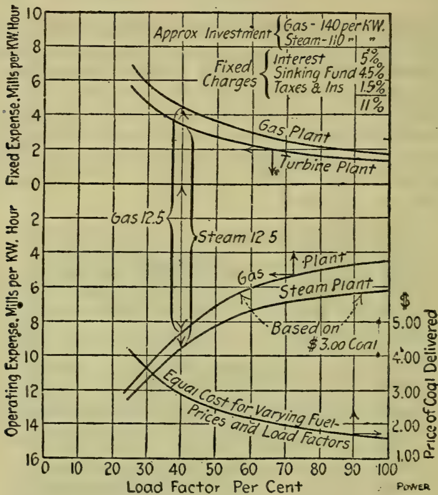


Fig. 3. Comparative operating expenses.

Mechanical and Thermal Efficiency of Internal Combustion Engines. T. C. Ulbricht and C. E. Torrance in Power give the following: *Mechanical Efficiency.* From a large number of values obtained from American manufacturers and operators, the following average table was derived for the mechanical efficiencies of engines operating on various fuels:

	Per cent.
Producer gas	82.0
Natural gas	84.0
Illuminating gas	84.2
Gasoline	87.7
Oils	84.8

These averages are on the basis of fuel used, instead of the engine type and in the case of gasoline and oils, are somewhat above the values usually obtained. However, the averages for the three gases are just what might be expected on any commercial test.

Thermal Efficiency. The thermal efficiency of a gas engine is rather indefinite, unless it is stated whether it is based on the work developed in the cylinder, or on that delivered at the brake.

In this investigation all thermal efficiencies have been referred to the brake h.p. per cylinder per end, so that a builder or purchaser may know just what per cent of the total heat units put into an engine is obtained at the brake as useful work.

To obtain data for determining the average thermal efficiencies of American engines, letters were sent to about 90 of the largest manufacturers in the United States, requesting guarantees on the brake horsepower, thermal efficiency on this basis, kind and calorific value of fuel upon which the guarantee was based, and variation of guarantee, if any, with the size of engine.

The thermal efficiencies were mostly calculated from the guaranteed fuel consumption at full load, by the formula,

$$\textit{Thermal efficiency} = \frac{2545}{\textit{B.t.u. per brake h.p.}}$$

the numerator being the B.t.u. equivalent of one h.p.-hr.

The curves, Figs. 4 to 11, show the results as obtained in most cases from actual guarantees given by the manufacturers, and since the tendency seems to be to under-rate the engines, or place the guarantee on the safe side, it would seem that these average curves represent good practice and are too low rather than too high.

Fig. 4 shows the average thermal efficiency curve for engines using kerosene. Where possible, Guldner's values for German practice have been plotted on the same sheet with those representing American practice. For kerosene, Guldner's curve is found to be below the average for American practice. This discrepancy is probably due to the fact that when Guldner wrote, some 10 years ago, very few oil engines had been developed, and the thermal efficiency was consequently low.

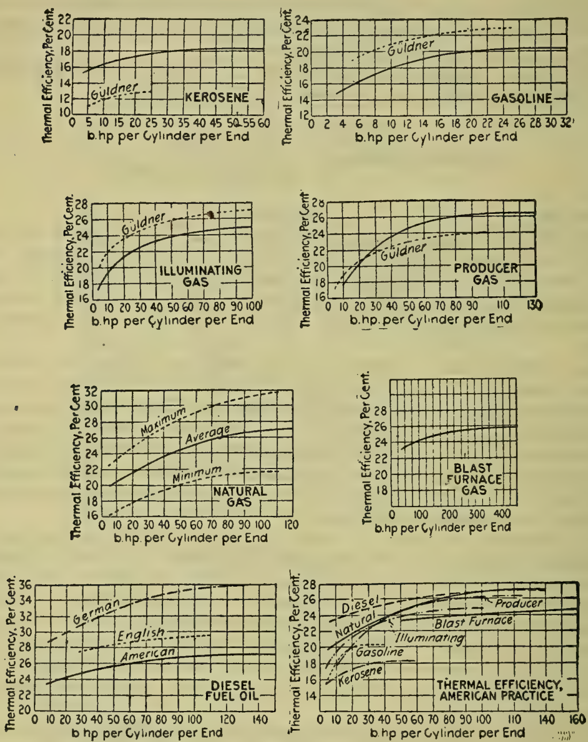
The thermal efficiency is seen to increase with an increasing brake-h.p., approaching 18.4% above 40 brake h.p. Fig. 5 shows the average thermal efficiencies for gasoline, which is lower than Guldner's curve for German practice. This would indicate either a higher development of the German gasoline engine, or a too conservative guarantee by the American builder. The efficiency is low for small horsepowers, but increases until above 23 brake h.p. where it reaches a maximum value of 20.4%. Guldner's value at 25 brake h.p. is 23%.

Fig. 6 also shows that for illuminating gas, Guldner's curve lies above that for American engines. At 100 brake h.p., American practice shows 25%, while German practice shows 27%. For producer gas, American practice in general gives results higher than the German, as will be seen from Fig. 7.

As may be expected, due to the great variation in the anlysis of natural gas, there is a wide range in the thermal efficiencies of engines using this fuel. (Fig. 8.) Therefore the average maximum and minimum curves are given. German practice does not include this gas. The average curve reaches a maximum of 27.3%

at about 120 brake h.p. Very few values were obtainable for blast-furnace gas, but the curve, Fig. 9, is what might be expected from good practice, showing a maximum of about 26% above 400 brake h.p.

Special efforts were made to obtain values for the Diesel engine, and the result (Fig. 10) shows the German values of thermal effi-



Figs. 4–11.

ciency to be highest, the English somewhat lower and the American still lower. This may be accounted for both by the longer period of development of this engine abroad and the higher quality of workmanship in Germany than in other countries.

Fig. 11 shows all the preceding average curves, for American practice only, reduced to the same scale for comparison.

Cost Formula for Internal Combustion Engines. A. A. Potter in Power, Dec. 30, 1913, gives the following formulæ:

Type	Capacity	Equation of cost in dollars
Gas engines	Up to 300 h.p.	$33.6 \times$ h.p.— 115
Gasoline engines, hit-and-miss governor	Up to 100 h.p.	$63.8 \times$ h.p.— 316
Gasoline engines, throttling governor	Up to 75 h.p.	$141 + 24.8 \times$ h.p.
Oil engines	Up to 400 h.p.	$309 + 36.1 \times$ h.p.
Producer gas engines, American mfg.	Up to 300 h.p.	$400 + 33.5 \times$ h.p.

Effect of Elevation upon the Power of a Gas Motor. R. E. Mathot in Engineering Magazine, Feb., 1907, states that each 100 meters (328.1 ft.) of additional elevation causes a loss of 1% in the power output of the gas motor.

Economic Limits Between which Prime Movers of the Various Types may be Advantageously Used. We quote Table I after R. E. Mathot in Engineering Magazine, 1907.

TABLE I. ECONOMIC LIMITS FOR PRIME MOVERS

Type of engine or motor.	Power limits within which the type may be practically employed, h.p.	Normal consumption per horse-power hour at full load. Steam, lbs.	Fuel, lbs.
Stationary steam engines			
Slide-valve non-condensing	15 to 50	37.5	5.5
Slide-valve, condensing	30 to 100	22	3.3
Corliss or Sulzer, simple condensing	50 to 200	17.5	2.5
Idem, compound	80 to 1000 and upwards	13	1.85
Semi-portable steam engines			
Simple, non-condensing	20 to 50	16.5	2.4
Simple, condensing	40 to 80	13.	1.9
Compound, condensing	60 to 300	9.5	1.35
Triple-expansion, condensing with superheat	300 to 500	7.6	1.1
Steam turbines			
Condensing	500 to 1000 and upwards		
Internal-combustion motors			
Illuminating gas	1 to 30	17.50 cu. ft. of gas	
Oil	1 to 20	0.75 lbs. oil	
Producer gas, suction	15 to 300	0.88 " coal	
Producer gas, pressure	100 to 1000 (and over).	1.00 " coal	
Diesel	50 to 500	0.42 " oil	

The limits indicated above of course are not absolute. Many small steam engines with vertical boilers are in use, for example, in units of very few horse-power each.

Prime Movers for Central Stations. Edwin E. Dreyfus read the following notes in a paper before the annual convention of the

Association of Iron and Steel Electrical Engineers in New York, Sept. 28, 1911.

The curves, Figs. 12 and 13, were presented to show the superior efficiency of the internal combustion engine within certain ranges, and also the increased uniformity in efficiency above other types. Oil engines led with an efficiency of 30% to 33%, referred to the shaft h.p., whereas gas engines ordinarily showed about 23% to 26% on

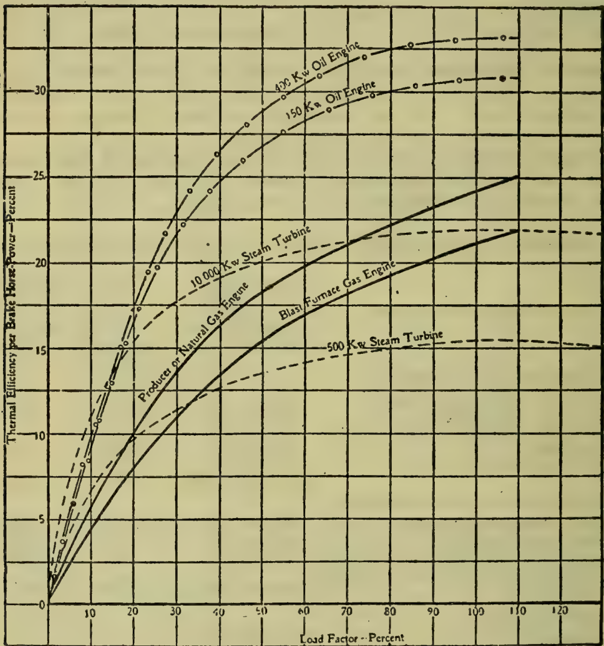


Fig. 12. Ordinary thermal efficiencies of main units based on total heat value per brake h.p., with no allowance for auxiliaries.

the same basis. Steam piston engines and turbines had a wide range of thermal efficiency between less than 5% and 21% on brake h.p. tests.

Mr. Dreyfus pointed out as a characteristic feature of the gas plant that the cost steadily decreased until two or more 2,000 k.w. units are run, whereupon the investment begins to increase directly with the installed capacity. Conversely the k.w. cost on the steam turbine station constantly diminishes with increase in

size. Therefore the ratio cost of steam and gas stations must constantly grow in favor of the former.

Cost of Power for Pumping with Internal Combustion Engines Using Various Fuels. The report of committee on Water Supply of American Railway Bridge and Building Association, abstracted in Engineering and Contracting, Nov. 26, 1913, states that a series of tests were made pumping from an 8-in. well, 190 ft. deep, lifting water against 15 ins. of vacuum, with a total head of 61ft. An 8 by 10-in. single cylinder double acting pump was used, direct

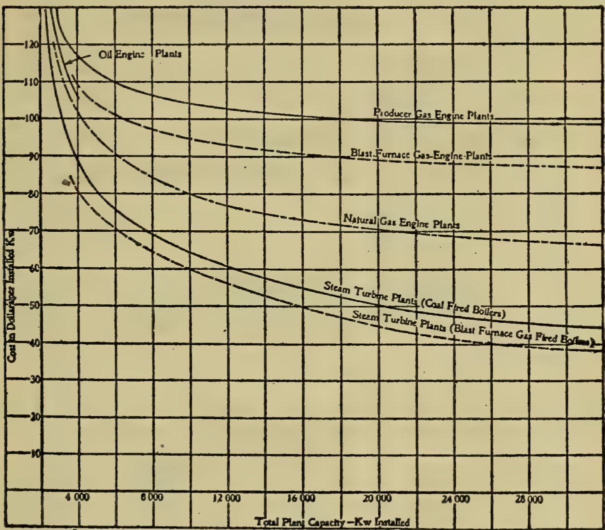


Fig. 13. Plant instalment costs of normal rated units, including buildings and foundations.

connected to a 6 h. p. four cylinder horizontal gasoline engine equipped to run on kerosene and distillate as well as gasoline, controlled by a throttling governor. The fuels used and the results of the fuel tests are given in Table 1A.

Comparative Costs with Various Fuels. The following tables were rearranged from data given in Isolated Plant, May and June, 1913:

Internal combustion engines are naturally divided into two general groups: (1) those that depend upon instantaneous combustion of the charge, or explosive engines, and (2) those in which the combustion is more gradual and in which the burning of the fuel occurs during a considerable portion of the expansion stroke. It is to the first group that internal combustion engines operating

TABLE 1A. COST OF FUELS FOR INTERNAL COMBUSTION ENGINES

Distillate	40. deg.	Baume	Flash ... 150	Burn ... 145
Methyl alcohol	40.5 deg.	Baume	Burns at same temperature.	
Kerosene	46. deg.	...	Flash ... 124	Burn ... 170
Gasoline	62. deg.	...	Burns at same temperature.	
Motor spirits	58. deg.	...	Burns at same temperature.	

	Distillate.	Alcohol	Kerosene	Gasoline	Motor Spirits
Lbs. fuel per hour	5.145	6.062	4.943	5.373	4.755
Cost fuel per hour, dollars	0.0347	.35	.06	.1313	.0975
Pump rev. per min.	43.35	43.32	43.54	43.72	43.79
Pumped, gal. per min.	175.	177.8	176.8	176.8	178.1
Water horsepower	2.69	2.73	2.72	2.72	2.74
Lbs. of fuel per hp.-hr.	1.91	2.22	1.91	1.97	1.74
Cost of fuel per hp.-hr.	$0.0129	$0.1282	$0.0220	$0.0483	$0.0356
Cost of fuel per gallon	$0.04625	$0.40	$0.08	$0.15	$0.13
Pints per hour	6	7	6	7	6
Temperature of cyl. start, deg.	165	90	135	46	46
Temperature of cyl. run, deg.	145	145	145	130	125
Temperature on inlet air, deg.	110	125	120	60	60

on gases and gasoline, or other easily volatized liquids belong and, as little difference in design or equipment exists in engines particularly adapted to such fuels, the economic value of an installation depends almost entirely upon the price of the dynamic agent in any given locality.

The engine room operating cost of all explosive engines operating on gases and easily volatized liquids is very nearly the same — estimate based on a plant of 250 h. p.— and conservative figures are given in Tables II and III. These fixed charges will vary to

TABLE II. OPERATING COSTS OF GAS ENGINES BASED ON A PLANT OF 250 H.P.

	Per h.p.
Cost of plant:	
Building	$10
Engine, foundations, piping, etc.	28
Miscellaneous	2
Total	$40
Cost of Power:	
Depreciation, 5% of total cost	$ 2.00
Repairs	0.80
Interest	2.40
Insurance	0.60
Taxes	0.60
Total fixed charges per year	$6.40
Fixed charges per hr. 3000 hrs. per year	0.00213
Attendance per h.p.-hr.	0.00125
Supplies, oil waste, etc., per h.p.-hr.	0.00029
Fuel, distillate gas, at 10 M. cu. ft.	0.0015
Total cost of power per h.p.-hr.	$0.00517

TABLE III. OPERATING COSTS OF GAS ENGINES BASED ON A PLANT OF 250 H.P., USING PRODUCER GAS

	Per h.p.
Cost of Plant:	
Producer building	$ 5
Producer, scrubber, piping, etc.	32
Miscellaneous	3
Engine room building	8
Engines, foundations, piping, etc.	40
Miscellaneous	2
Total	$90
Cost of Power:	
Depreciation at 5%	$ 4.50
Repairs at 2%	1.80
Interest at 6%	5.40
Insurance at 1½%	1.55
Taxes at 1½%	1.13
	$14.48
Fixed charges per h.p.-hr., 3000 hrs. per year	$0.004827
Attendance, producer, per h.p.-hr.	.00107
Supplies, etc., producer, per h.p.-hr.	.00015
Attendance engine room	.00125
Supplies, etc.	.00028
Fuel, anthracite coal at $5 per ton	.0025
Total cost of power per h.p.-hr.	$.010077

a certain extent, but, as they represent but a part of the "cost of power" that decreases in proportion as the cost of fuel increases, may be safely considered as constant for all practical purposes. The consumption of fuel is very nearly inversely proportional to the heating values of the various fuels, which will be considered not in order of their caloric value, but in order of their value as economic agents in "cost of power" production.

Cost of Power Generation in Small Plants. Engineering Magazine beginning October, 1911, published a series of articles by Robert L. Streeter on the Internal Combustion Engine in Modern Practice. From the fourth article of the series appearing in the Jan., 1912, issue we have abstracted the following cost data:

In the following discussion it is assumed that the question of which power to install hinges entirely on the cost of the power, there being no restrictions as to convenience or space required or any other condition which will make either steam, gas, or oil engines more desirable than either of the other two. The discussion that follows, then, will deal simply with the cost of power generated in an isolated plant for a specific purpose. Three types of engines will be taken up, steam, producer-gas, and liquid-fuel.

The difference in location of plants results in difference in the cost of fuel, and this difference is often large enough to make an appreciable change in the cost of power which must be accounted for. Hence the discussion, to be of value, must be on plants of various powers and for fuels at different prices.

The form of power that is to be generated is of importance. In this paper, in order to have uniformity, it is assumed that in each case the engine is direct-connected to a direct-current dynamo, the current to be used for lighting and power in a manufacturing plant, during a working day of 10 hrs., 6 days per week, or 300 days per year. The sizes of the plants selected will be 20, 100, 250 and 500 k.ws. output of the generator. In no case will the cost of the land or building be included, as it is impossible to get even an approximate figure that would be of value for those items.

In general, the costs of the machines included in the following discussion were secured from manufacturers. The prices in each case represent a mean of those submitted, in some cases 5 or 6, in other cases only 2. The cost of the foundation in each case was based on the floor space required, and of piping on the cost of piping in similar plants. The cost of the machines in each case includes erecting, freight for three or four hundred miles, cartage, etc.

The fixed charges were apportioned for the steam and producer gas plants as follows:

	Per cent.
Interest on investment	5
Depreciation	5
Repairs	2
Taxes	1
Insurance	1
Total	14

The depreciation will probably not be the same on all parts of the plant, nor will the cost of repairs be uniform over the whole plant, but such figures as were selected represent the average depreciation and repairs on the whole plant. For the high-pressure oil plants the depreciation was assumed to be 5½% and the repairs 2½%, for it has been the experience that these plants do cost more to keep in repair than plants where working pressures are not so high.

Since no plant can be expected to run at full power all the time, a load factor must be chosen. Since the assumption has been made that the plants under discussion will be used to run a manufacturing plant, a high load factor may be used, at least 75%. If these plants were to sell power for motors and lighting, we might expect a much lower factor.

The wage of a first-class engineer for the larger plants was assumed at $4 per day, firemen $2.50 per day, and for second-class engineers for the smaller plants, $2.50 per day. In the smaller plants and in all the oil-engine plants there was no allowance made for a night man.

The coal is based on a heating value of 13,000 B. t. u. per lb., oil on 19,000 per lb. The price of water was assumed to be 10 cts. per 1,000 gals., lubricating oil 22 cts. a gal., and cylinder oil 30 cts. per gal.

The comparative costs appear as follows:

20-KW. STEAM PLANT

Brake h.p.	32
Indicated h.p.	35
	Cost
Engine and foundation	$800
Generator and switchboard	600
Vertical boiler, foundation and piping	450
Total	$1,850
	Cost per year
Coal, 220 tons at $4	$880
Labor	750
Fixed charges at 14%	260
Oil, waste and supplies	125
Water	50
Total	$2,065

The cost per k.w.-hr. at 75% load would be 4.6 cts.

For the engine of this plant the assumption is of the high-speed horizontal type to be run non-condensing. The type of boiler selected was the vertical fire-tube on account of the low cost, being $125 less than the return-tubular horizontal type.

The coal consumption was based on, first, efficiency of boiler 60%, and second, steam consumption of engine 35 lbs. per 1 h. p. per hr. An additional 15% was allowed on the coal for banking, and losses.

The water cost was found by the assumption of 35 lbs. per 1 h. p. hr. at 75% load, allowing 15% for leakage, blow-off, etc,

20-KW. PRODUCER-GAS ENGINE PLANT

Brake h.p. of engine	32
	Cost
Engine and foundation, and air compressor	$1,200
Producer and gas	735
Generator and switchboard	600
Total	$2,535

	Cost per year
Coal, 75 tons at $4	$300
Labor	300
Fixed charges, 14% on cost	355
Oil, waste and supplies	135
Water	110
Total	$1,200

At 15 kw. or 75%, the total cost per kw.-hr. would be 2.68 cts.

For the producer plant an anthracite suction producer was chosen because they are more applicable to small powers than the bituminous producer, although bituminous producers are made as small as 50 h. p.

The coal for this installation was based on 2 lbs. per h. p., including standby losses. The care of a plant of this size will not take the full time of one man; in fact, less than half of it; hence the lâbor cost of $300. The cost of water was based on 2 cu. ft. per kw.-hr. for the entire plant, fresh water to be used continuously.

KW. LOW PRESSURE OIL-ENGINE PLANT

	Cost
Engine, foundation and oil tank	$1,600
Generator and switchboard	600
Total	$2,200

	Cost per year
Fuel oil, at 3 cts per gal.	$300
Labor	200
Fixed charges, 14% of cost	308
Oil, waste and supplies	125
Water	40
Total	$973

At 15 kw. or 75% load, the cost per kw.-hr. will be 2.1 cts.

For the 20-kw. oil-engine plant a low-pressure oil engine was used because high-pressure oil engines are not made in that size in the United States. In the low-pressure oil engine the charge is compressed to about 60 or 70 lbs., when it is exploded by coming in contact with the heated combustion chamber. In the high-pressure engine, air alone is compressed to from 300 to 600 lbs. per sq. in. and oil is injected into this highly compressed air at about the end of the stroke. At the higher compression, 500 to 600 pounds, the temperature due to the work of compression is sufficient to ignite the oil as it enters the cylinder. Where the lower limit of compression is used, 300 to 400 lbs., the heat of com-

pression is not relied on to ignite the oil, but a vaporizer remains heated from the previous explosions. The efficiency of the high-pressure engine is approximately twice that of the low-pressure engine.

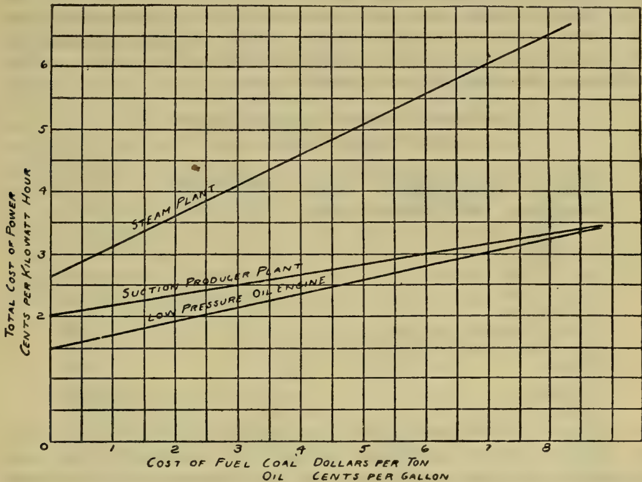


Fig. 14. Cost of power from steam, oil, and producer-gas engines in 20 kilowatt units.

The fuel for the 20-kw. low-pressure engine is based on 1 lb. per h.p.-hr. at 75% rating. The water was based on 5½ gals. per h.p.-hr.

100-KW. STEAM PLANT.

Output in kw., 100.

Indicated h.p. of engine, 160.

	Cost
Engine and foundation	$3,000
Boiler and pump (erected) and piping	4,400
Generator and switchboard	1,600
Steel stack and foundation	500
Total	$9,500

	Cost per year
Coal, 800 tons at $4	$3,200
Labor	1,650
Fixed charges, 14% of cost	1,330
Oil, waste and supplies	175
Water	150
Total	$6,505

At 75 kw. or 75% load, the kw-hr. cost is 2.89 cts.

For this plant a high-speed non-condensing engine was assumed,

as it would hardly be practical to put in a condensing engine of that size. The reason is that the condensing plant would cost much more. The fixed charges on this cost, together with the cost of steam for auxiliaries and the cost of condensing water, would outweigh the saving in coal.

The boiler in this case was assumed to be a standard water-tube. The coal and water cost were based on boiler efficiency of 60%, engine to take 30 lbs. steam per indicated h.p.-hr. at 75% load factor, allowing 15% for standby losses.

100-KW. SUCTION-PRODUCER PLANT.
Brake h.p. of engine, 150.

	Cost
Engine and foundation and air compressor	$5,700
Producer and piping	2,200
Generator and switchboard	1,600
Total	$9,500

	Cost per year
Coal, 275 tons at $4	$1,100
Attendance	750
Fixed charges at 14%	1,330
Oil, waste and supplies	175
Water	500
Total	$3,855

At 75 kw. or 75% load, the cost per kw.-hr. is 1.71 cts. For this plant, a suction producer operating on anthracite coal was assumed, as the most convenient and the cheapest. A bituminous producer of this size would cost about $3,000 to install, compared with $2,200 for the anthracite producer.

The type of engine assumed for this installation is the three-cylinder vertical. The coal for the engine was based on 1½ lbs. per brake h.p. hr. at 75% load factor, 10% being added for standby losses. The water was based on 15 gals. per h.p. hr., 5 for engine and 10 for producer and scrubber, using the water only once.

100-KW. HIGH PRESSURE OIL ENGINE.
Brake h.p., 150.

	Cost
Engine and foundation	$11,500
Generator and switchboard	1,600
Total	$13,100

	Cost per year
Fuel oil, 25,000 gals. at .03	$ 750
Labor	750
Fixed charges at 15%	1,965
Oil, waste and supplies	175
Water	170
Total	$3,810

Kw.-hrs. per year, 225,000. Cost per kw.-hr., oil at .03 per gal., 1.69 cts.

The term "high-pressure oil engine," in the discussion, has been applied to the type of engine in which air alone is compressed during the second stroke of the cycle and the liquid fuel is sprayed into the cylinder with the help of highly compressed air during the first part of the expansion stroke. The item of engine cost includes all auxiliaries, tanks, oil pump, air compressor, etc. The fuel cost is based on .55 lbs. per brake h.p. hr.

If a low-pressure oil engine had been assumed instead of a high-pressure, the first cost would have been about $4,000 less for the entire plant. In that case the fixed charges per year would have been 14% of $9,100, about $1,275. The saving on this item would thus be $685 per year. The oil consumption for the low-pressure engine would be about 46,000 gals. per year, cost $1,380, against $750 for the high-pressure. Hence, the net cost per year for the low-pressure engine would be about $55 less than for the high-pressure engine if the above assumptions of fixed cost and fuel consumption are correct. If the fuel costs 3½ cts. per gal., the difference in yearly cost of the two engines would be $75 in favor of the high-pressure engine.

250-KW. STEAM PLANT.

Indicated h.p., 385.

	Cost
Engine and foundation	$ 5,850
Boilers, pumps and piping	5,600
Steel stack and flues	600
Generator, switchboard and wiring	4,000
Total	$15,650

	Cost per year
Coal, 1,500 tons at $4	$ 6,000
Labor	2,000
Fixed charges at 14%	2,240
Oil waste and supplies	225
Water	335
Total	$10,800

At 75% load, 187.5 kw., the cost per kw. hr. at the conditions assumed above would be 1.92 cts.

For this size steam plant a non-condensing tandem-compound Corliss engine was assumed. The steam consumption of the engine would be about 22 lbs. per 6 h.p. hr. This figure was used to get the size of the boilers and the coal consumption. In working out the coal consumption 10% was allowed for auxiliaries and 10% for standby losses.

250-KW. ANTHRACITE SUCTION-PRODUCER PLANT — ONE UNIT.

Brake h. p. 365.

	Cost
Engine and foundation, and air compressor	$13,000
Producer and piping	5,125
Generator, switchboard and wiring	4,000
Total	$22,125

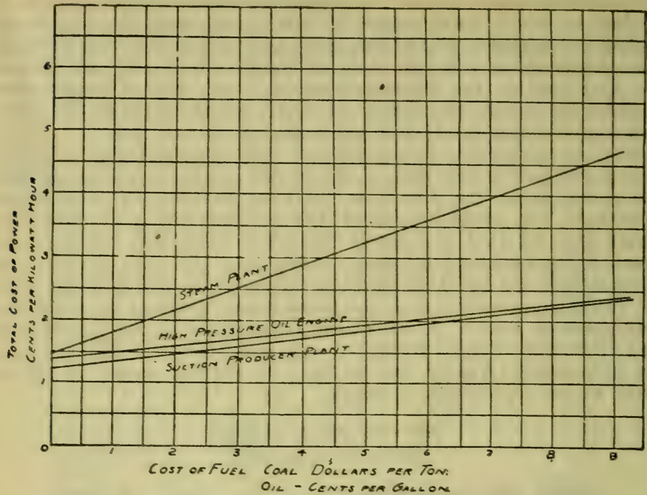


Fig. 15. Comparative generating costs, steam, oil and gas engines, 100-kilowatt units.

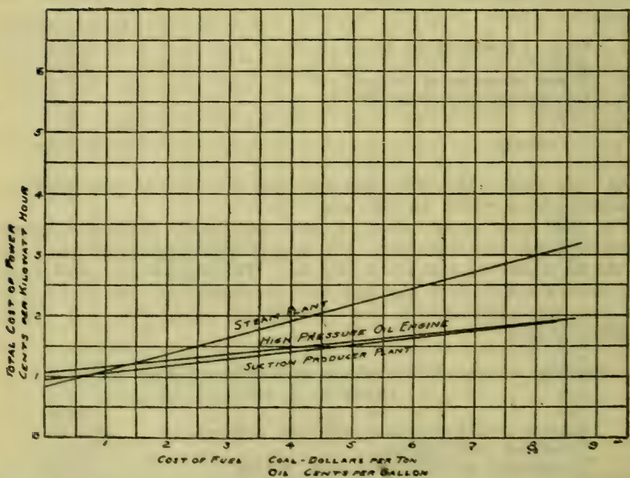


Fig. 16. Comparative generating costs, steam, oil, and producer gas engines, 250 kilowatt units.

	Cost per year
Coal, 625 tons at $4	$2,500
Labor	1,500
Fixed charges at 14%	3,100
Oil, waste and supplies	225
Water	600
Total	$7,925

Kw. hrs. per year at 75% per load factor, 562,000. Cost per kw. hr., 1.40 cts.

The engine assumed for this plant is a 4-cylinder vertical, gas furnished by one anthracite producer. The coal cost was based on 1.5 lbs. per brake h.p. hr., including standby losses, at 75% load. The water is based on 7½ gals. per brake h.p. hr., using the scrubbing water over and over.

250-KW. OIL-ENGINE PLANT

Brake h.p. 365.

	Cost
Engine foundation and piping, oil tanks, pump, etc.	$26,700
Generator, wiring and switchboard	4,000
Total	$30,700

	Cost per year
Fuel oil 57,000 gals., at .03	$1,710
Labor	900
Fixed charges at 15%	4,600
Oil, waste and supplies	225
Water	400
Total	$7,835

Kw.-hrs. per year at 75% load factor, 562,000. Cost per kw.-hr., 1.4 cts.

The cost of fuel for this plant is based on one-half lb. of oil per brake-h.p.-hr. at 75% load.

500-KW. STEAM UNIT, COMPOUND-CONDENSING ENGINE

Brake h.p., 750.

	Cost
Engine and foundation	$ 9,300
Boilers and pumps	10,000
Stacks and flues	1,200
Condenser	2,000
Generator, switchboard and wiring	9,500
Total	$32,000

	Cost per year
Coal, 2,500 tons at $4	$10,000
Labor — 3 men: 2 days, 1 night	2,600
Fixed charges at 14%	4,480
Oil, waste and supplies	400
Water	420
Total	$17,900

Cost per kw. hr. at 75% rating = 1.59 cts.

For the 500-kw. steam plant a compound-condensing Corliss engine was assumed. The steam consumption was figured on 18 lbs. per 1 h.p.-hr. for the main engine at 75% load, with 20% added for auxiliaries and stand-by losses. It was also assumed that condensing water could be had for no cost except pumping, which is allowed for in the cost of the plant and steam for auxiliaries.

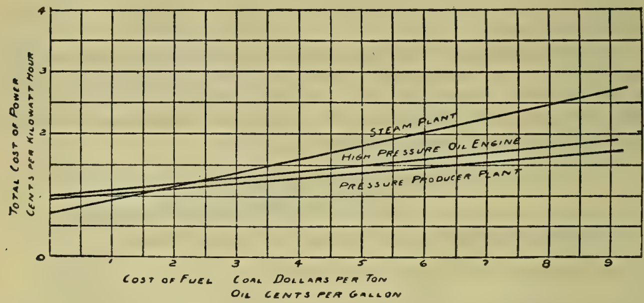


Fig. 17. Comparative costs of power generations, steam, oil, and producer-gas engines, in 500-kw. units. Includes all costs except land or buildings.

PRESSURE-PRODUCER PLANT.

Brake h.p., 725

	Cost
Engine, piping, foundation and air compressor	$25,000
Producers and auxiliaries	13,000
Generator, switchboard and wiring	9,500
Total	$47,500

	Cost per year
Coal, 1,020 tons at $4	$4,080
Labor	2,600
Fixed charges at 14%	6,640
Oil, waste and supplies	400
Water	1,000
Total	$14,720

Cost per kw.-hr. at 75% rating = 1.31 cts.

For this producer plant a bituminous producer was assumed for several reasons, one of which is that the size is large for one suction producer, and in this discussion we are limited to one unit in each case for sake of uniformity. The bituminous producer is well adapted to this size of unit and it is well to know the possibilities of such an installation. The cost is more than for a plain suction producer, but efficiency is probably higher; certainly this type of producer is more flexible.

The coal cost is based on 1.25 lbs. per h.p. hr. at 75% load, including all stand-by losses. The water is based on 7½ gals. for

the engine, producer and scrubber. In this case the water for the scrubber will have to be used over and over. If this is not done the water consumption will be doubled. In order to make it possible to use this water continuously it should be cooled by spray nozzles after being run into a settling tank where the dust from the scrubber is deposited. This cost of the tank, nozzles, etc., has been taken care of in the cost of producers and auxiliaries.

HIGH-PRESSURE OIL ENGINE. ONE UNIT.

Brake h.p., 725.

	Cost
Engine, foundation and piping, oil tanks, pumps, etc.	$50,500
Generator and switchboard	9,500
Total	$60,000

	Cost per year
Fuel oil, 112,000 gals. at .03	$ 3,360
Labor	1,200
Fixed charges at 15%	9,000
Oil, waste and supplies	400
Water	840
Total	$14,800

Cost per kw. hr. at above conditions, 1.32 cts.

The cost of fuel oil for this engine is based on ½ lb. per brake h. p. hr., the water on 5 gals. per h.p. hr. at 75% load.

In the foregoing tables the cost of power per kw. hr. given in each case is based on coal at $4 per ton, or oil at 3 cts. per gal. To show the variation in the cost of power for different costs of fuels, the diagrams shown in Figs. 14 to 17 have been worked out for plants of 20-, 100-, 250-, and 500-kw. capacity respectively. The cost of power as shown by the diagrams represents the same conditions as given in the text except for the costs of fuel. Land and building are not included in any case.

While the foregoing tables and diagrams cover the cost of power generated by engines burning the fuels that are generally found in use, in some cases other fuels may be used for special reasons. Among these fuels are natural gas, illuminating gas and gasoline. It would make this discussion too long to take up these fuels in the same way that the steam, producer and oil-engine plants were treated, but in order to give some idea of the cost of power as generated from these fuels, a specific plant, 100-kws., will be taken up for each one.

NATURAL-GAS PLANT

Brake h.p. of engine, 150

	Cost
Engine, foundation and piping	$6,000
Generator and switchboard	1,600
Total	$7,600

	Cost per year
Gas, 3,810,000 cu. ft. at 20 cts.	$762
Labor	750
Fixed charges at 14%	1,064
Oil, waste and supplies	175
Water	170
Total	$2,921

At 75% load factor the cost per kw. hr. would be 1.30 cts.

ILLUMINATING-GAS PLANT

Brake h.p. of engine, 150

	Cost
Engine, foundation and piping	$6,000
Generator and switchboard	1,600
Total	$7,600

	Cost per year
Gas, 5,740,000 cu. ft. at 60 cts.	$3,444
Labor	750
Fixed charges at 14%	1,064
Oil, waste and supplies	175
Water	170
Total	$5,603

At 75% load factor the cost per kw. hr. would be 2.49 cts.

The cost of gas for the two preceding plants was based on an efficiency of 25% at 75% load. For the natural-gas plant this means a consumption of 11.3 cu. ft. per brake h.p. hr. with gas having a heating value of 900 B. t. u. per cu. ft. For the illuminating gas the figures are 17 cu. ft. per brake h.p. hr. when the gas has a heating value of 600 B. t. u. per cu. ft. The diagrams shown in Figs. 18 and 19 represent the cost of power generated by the above plants with varying prices of fuel. The conditions assumed here are the same as for the previous diagrams; that is, the cost includes everything except land and building.

Comparison of Fuel Cost. The following tables showing (1) the cost per h.p. of oil engines with the fuel consumption for various load factors as guaranteed by the maker of one of the latest and most improved oil engines on the market; and (2), a comparison of fuel cost for different types of power plants based on a size of 80 h.p. and a load factor of three-quarters full load, were abstracted from The Isolated Plant, June, 1909.

Load factor	Oil per brake, h.p. hr.	Brake, h.p. hrs. per gal.	Fuel cost per brake, h.p. hr. Oil at 2.8 cts. per gal., cts.
Full load	0.6	12.5	0.22
¾ "	0.6	12.5	0.22
½ "	0.65	11.5	0.24
¼ "	1.05	7.1	0.39

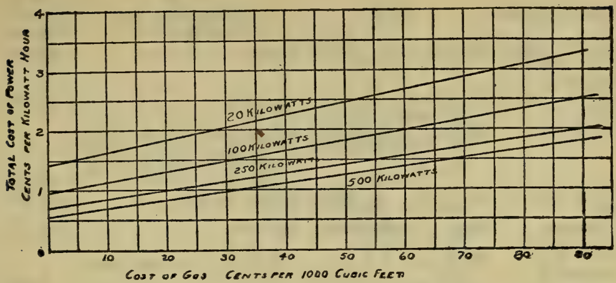


Fig. 18. Cost of power generation, natural-gas engines in 20-, 100-, 250- and 500-kw. units. Cost of land and buildings not included.

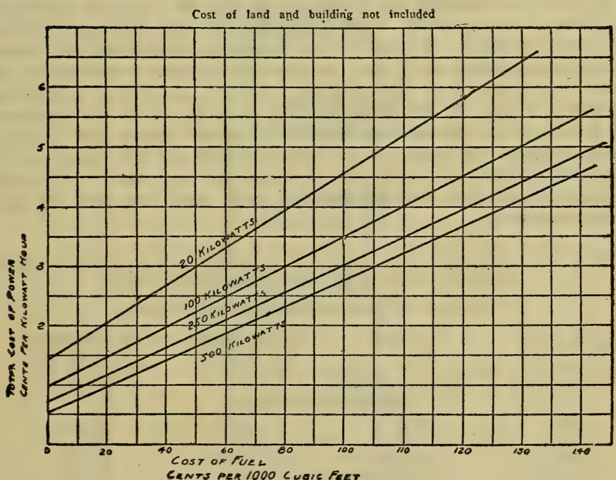


Fig. 19. Cost of power generation from illuminating-gas engines in 20-, 100-, 250- and 500-kw. units. Cost of land and building not included.

Type of engine	Fuel.	Consumption per brake h.p. hr.	Cost per brake, h.p. hr.
* Simple slide valve steam engine.	Bituminous coal, $2.75 per ton.	6 lbs.	$8.25
Gasoline engine.	Gasoline, 12 cts. per gal.	1/10 gal.	12.00
Gas engine.	Illuminating gas, 80 cts. per 1,000 cu. ft.	At 12,000 B.t.u.— N. Y. gas about 565 effective B.t.u.= 21 cu. ft.	16.80
Electric motor.	Current, 5 cts. per kw. hr.	0.85 k.w.-hr.	42.50
* Producer gas engine.	Pea, anthracite, $3.50 per ton.	1.4 lbs.	2.45
Most improved oil engine.	Fuel oil, 2.8 cts. per gal. tank car lots.	0.6 lb. (7½ lbs. per gal.)	2.24

* Standby losses of 108 hrs. per week. There were no standby losses for the other engines.

An interesting fact is that the consumption is nearly the same whether kerosene, fuel oil or crude oil be used.

Fuel Consumption Tests of Small Oil and Gasoline Engines. W. E. Donner obtained the following figures at the tests conducted at Clarks, Nebr., which were published in the Electrical World for April 12, 1913. An effort was made to determine the output for a consumption of 1 gal. of fuel at various loadings of the engine and generator. Tests were made on an Alamo 35-h.p. engine using 39 deg. B. distillate for fuel (which cost 10 cts. per gal.), and a Fairbanks-Morse commercial gasoline engine set. The oil engine carried an overload of 220 amperes at 120 volts for an hour, the gasoline unit refused to carry any overload. In making the calculations 5% was allowed for belt loss, and 85% for generator efficiency.

TABLE IV. TESTS OF SMALL ALAMO AND FAIRBANKS-MORSE ENGINES AT CLARKS, NEB.

(One gal. of fuel oil used on each test.)

Kw.-hr. delivered at switchboard	Cost per kw.-hr. at switchboard	Oil consumed per kw.-hr. of engine, pints	H.p. delivered by engine, allowing for losses
	Alamo 35 h.p. Engine		
21.6	$0.0214	1.28	35.84
21.6	0.0214	1.28	35.84
20.87	0.0192	1.237	34.62
10.37	0.0386	1.5	17.20
5.12	0.0404	2.615	8.49
5.25	0.0347	2.237	8.71
	Fairbanks-Morse 25 h.p. Engine		
12.00	$0.0313	1.405	19.91

Fuel Economy of Small Gasoline Engines. The figures in Table V were derived under the direction of A. A. Potter, from tests of

TABLE V. FUEL ECONOMY OF GASOLENE ENGINES

Cylinder diam., in.	Stroke, in.	R.p.m.	Rated brake h.p.	Gasolene consumption per brake h.p.-hr. Full load Lb.	Full load Gal.	¾ load Lb.	¾ load Gal.	½ load Lb.	½ load Gal.	¼ load Lb.	¼ load Gal.
3.5	5.25	500	1.75	1.030	0.169	...	....	1.35	0.222	1.99	0.327
5.0	8.0	350	4.0	0.915	0.150	1.03	0.169	1.24	0.204	2.08	0.342
5.5	9.0	325	6.0	0.834	0.137	0.81	0.133	0.99	0.163	1.47	0.242
6.5	9.5	300	6.0	0.855	0.140	1.06	0.174	1.14	0.187	1.61	0.264
7.25	14.0	250	10.	0.791	0.13	...	....	1.46	0.24	...	....

the Kansas State Agricultural College, on 5 gasoline engines of different makes, and varying in power from 1¾ to 10 h.p.

All the engines tested were of the 4-stroke-cycle type, water cooled, governed by the hit-and-miss method and provided with a make-and-break ignition system. They are loaded by Prony brakes and the fuel accurately weighed, and 3 to 6 checks runs were made at each load, each run lasting 30 mins.

The gasoline used was 62 deg. B. and had a specific gravity of 0.731 at 60 deg. F., making the weight 6.09 lbs. per gal. The heat of combustion of the gasoline, as determined by a Junkers constant-pressure calorimeter was 19,411 B.t.u. per lb. (high), or 18,415 B.t.u. per lb. net.

The average results of the tests are given in the table, from which it is evident that 1.3 to 1.69 gal. of gasoline will be required to run the average small engine 10 hrs. at full load.

Cost of Producer Gas Power Plants. Prof. R. H. Fernald in Bulletin 55 of the Bureau of Mines gives the cost of gas engines and producers in sizes up to 3000 h.p. inclusive in Tables VI to VIII.

Prof. Fernald says considerable variation will be noticed in the prices quoted by different manufacturers for plants of the same rated capacity. In some cases this difference is warranted by a difference in the quality. In others it is due to a difference in the number of units installed to make up the total required horse-power or to different requirements for auxiliary equipment.

The following statements show the views of manufacturers in 1912:

1. The excessive cost will be reduced when increased demand cuts down the overhead expense of manufacture.

2. The excessive cost of plants, especially in the smaller sizes, seem to be a great drawback.

TABLE VI. COST OF GAS PRODUCERS (1912)

H.p.	Cost f. o. b. factory	Cost erected, including foundation
15	$396	.....
15	450	$500
25	455	.....
25	560	625
35	560	.....
50	700	.....
50	730	820
50	900	1,035
50	1,400	1,800
75	910	.....
75	940	1,050
100	1,050	.....
100	1,100	1,230
100	1,200	1,380
100	1,450	1,850
100	....	2,400
150	1,295	.....
150	1,530	1,710
150	1,600	1,840
150	....	3,300

H.p.	Cost f.o.b. factory	Cost erected, including foundation
200	1,725	.....
200	2,050	2,300
200	2,200	2,750
200	2,800	3,220
200	3,000	3,700
200	....	4,000
250	2,100	.....
250	2,600	2,900
250	3,500	4,300
250	....	4,750
300	2,700	3,500
300	3,200	3,600
300	3,400	3,910
300	....	5,700
500	6,000	7,000
500	8,500	10,000
500	....	9,400
1,000	12,000	13,500
* 1,000	14,500	17,000
1,000	....	18,700
† 3,000	40,000	44,000

* 2 times 500. † 5 times 600.

TABLE VII. COST OF PRODUCER-GAS ENGINES (1912)

H.p.	Cost f.o.b. factory	Cost of engine erected, including foundation
45	$1,950	$2,400
50	2,000	2,500
50	2,200	2,500
55	2,250	2,700
75	3,300	3,850
100	3,850	4,475
100	4,000	4,400
100	4,000	4,600
125	4,500	5,150
150	5,800	6,670
165	6,800	7,550
180	6,500	7,500
190	8,500	9,250
200	7,000	....
200	7,800	8,970
200	8,500	9,500
200	....	9,700
250	8,500	....
250	9,200	10,500
250	10,600	11,600
300	10,200	....
300	11,500	13,125
300	11,800	12,900
300	12,500	13,500
500	16,000	18,000
500	17,000	....
500	20,000	22,500
1,000	31,000	35,000
1,000	34,000	....
1,000	35,000	39,000
3,000	90,000	101,500

TABLE VIII. COST OF PRODUCER-GAS INSTALLATIONS (1912)

H.p.	Cost of gas producer and engine erected, including foundations	Cost of complete plant, exclusive of buildings *	Cost of complete plant, including buildings *
50	$4,300	$5,300	.....
100	6,250	7,800	$9,100
200	12,400	15,800	17,500
200	13,200	16,200	.....
250	14,800	18,200	.....
300	17,000	22,000	23,800
500	25,000	29,500	.....
500	32,500	47,500	.....
1,000	48,500	57,500	.....
1,000	56,000	84,000	.....
3,000	145,500	202,000	.....

* Includes producer, engine, electric generator, piping, switchboard, and auxiliaries, all erected with suitable foundations.

3. We believe that the cost of plants has been coming down in the past two or three years, but it is still rather high and future improvements will probably bring the figures down.

4. A good producer-gas power plant can be installed for just about the same money that would be required for a first-class condensing steam plant, and would show a material fuel economy over the latter. However, in the majority of small plants where producers would otherwise logically be used, the purchaser objects seriously to spending more money for a gas plant than would be required for an ordinary type of steam equipment. The large difference in fuel consumption does not seem to be important as compared with the additional investment required. We believe, however, that this handicap will soon be overcome.

Cost of Gas Engines. The costs of 300 and 400 h. p. 4-cylinder, double opposed type of well known heavy-duty gas engines of moderate speed are given in Table IX. Engines of this make are also to be had in 4 sizes in 2-cylinder type 75, 100, 150 and 190 h.p. and 2 sizes in single cylinder 35 and 50 h.p.

These engines are high tension ignition, 4-cycle type and are rated by actual brake h.p. tests.

The following prices are net, f.o.b. factory and cover engines for belted work only:

TABLE IX. COST OF GAS ENGINES

Size	Type		Price
35 h.p.	Single	cylinder	$1,100
50 h.p.	"	"	1,500
75 h.p.	Double	"	2,000
100 h.p.	"	"	2,500
150 h.p.	"	"	3,500
190 h.p.	"	"	4,500
300 h.p.	Four	"	6,500
400 h.p.	"	"	8,500

Another engine works builds gas engines of the 4-stroke cycle type in several designs as follows

I. Single-cylinder — 1. Single acting.
— 2. Double acting.
II. Two-cylinder (tandem) — 1. Single acting.
— 2. Double acting.

These engines are to be had in sizes of from 50 to 2,000 h.p.

The costs are f.o.b. factory for engine complete. An average cost of these engines is very close to $35 per h.p. with only slight variation in accordance to size, because of refinements which are necessary in the large units.

TABLE X. VERTICAL, SELF-CONTAINED TYPE, GAS ENGINES, FOUR CYCLE

H.p.	R.p.m.	No. of cylinders	Cost f.o.b. works
6	350	1	$ 405
20	300	2	765
50	275	3	1,800
100	250	3	2,925
150	250	3	4,050

Larger sizes made to order — the average price of which is $29.25 to $31.50 per h.p. for engines run on natural or city gas, and $36 to $41.50 per h.p. for producer gas operation.

The reason for the above variation, in prices for natural or city gas and producer gas engines, is the fact that when run on producer gas an engine must be about ⅓ larger size (gas engine rating) to develop an equivalent amount of power. That is, a 150 h.p. gas engine would only develop 100 h.p. if operated on producer gas.

The cost of gas producers averages about as follows:

Type	Cost per h.p., f.o.b., factory
Hard coal suction	$14
" " pressure	18
Soft " Suction	25
" " pressure	30

Producer Power Plant Costs. The estimated costs in Table XI were given in a report of the Hydro-Electric Power Commission of the Province of Ontario, Canada.

Formula for Cost of Gas Producers. A. A. Potter in Power, Dec. 30, 1913, gives the following formulae of costs:

Type	Capacity	Equation of cost in dollars
Suction	Up to 300 h.p.	$252 + 14.2 \times$ h.p.
Pressure	Up to 300 h.p.	$860 + 15.15 \times$ h.p.

Approximate Costs of Gas Power Installations. M. P. Cleghorn in Power, March 31, 1908, estimates the cost of complete gas power

TABLE XI. PRODUCER-GAS POWER, SHOWING CAPITAL COSTS OF PRODUCER-GAS PLANTS INSTALLED, AND ANNUAL COSTS OF POWER PER BRAKE, H.P.

Size of plant, h.p.	Capital cost of plant per h.p. installed. Machinery, etc.	Buildings	Total	Annual cost of 10-hr. power per brake h.p.	Annual cost of 24-hr. power per brake h.p.
10	$137	$40	$177	$53.48	$90.02
20	110	36	146	44.47	75.22
30	93	33	126	38.73	65.99
40	84	29	113	35.05	59.85
50	80	26	106	32.27	55.22
60	79	24	103	30.49	52.03
80	78	22	100	28.70	48.95
100	77	20	97	27.05	45.40
150	76	19	95	25.87	43.17
200	74	17	91	24.95	41.78
300	73	16	89	24.24	40.40
400	71	14	85	23.41	39.03
500	70	12	82	22.54	37.54
750	67	10	77	21.55	35.99
1,000	65	8	73	20.46	34.66

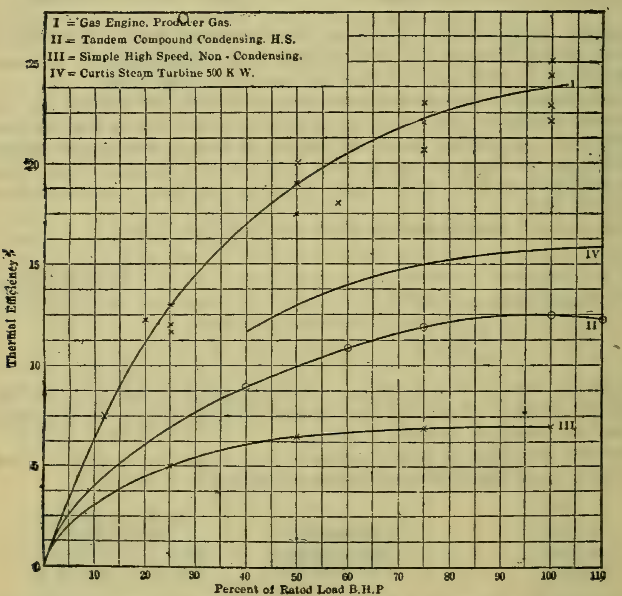


Fig. 20. Curves showing efficiency at full load and at less than full load.

plants, suction and pressure of capacities ranging from 50 to 1,500 brake h.p. for suction plants and from 100 to 3,000 brake h.p. for pressure plants. An extra unit is provided in each case, which allows for cleaning and repairs without interruption in the service. Each estimate includes gas producers, engines, direct-current engine-type generators, all necessary piping, air compressor, buildings and land, but does not include the station heating system. The waste heat from the engine could be utilized at a small outlay of capital for heating a large part of the building during working hours.

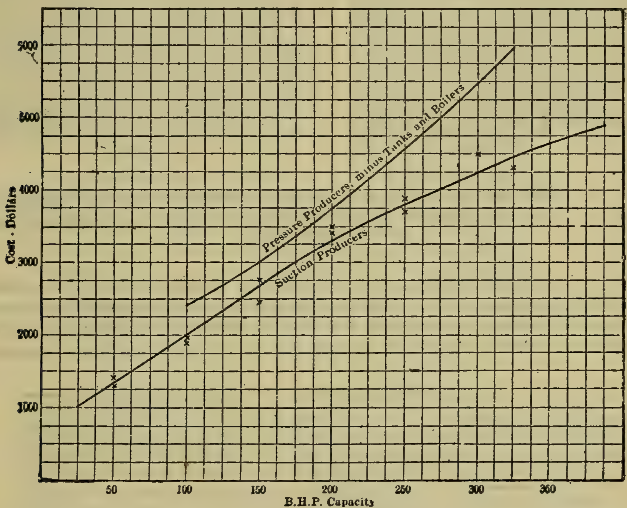


Fig. 21. Cost of gas producers, including cost of installing.

Kind and number of units. Vertical engines have been considered exclusively for the suction plants and in pressure plants up to 1,500 h.p., while in pressure plants of from 1,500 to 3,000 h.p. horizontal engines have been assumed. Since suction producers are not built larger than 350 h.p., the size of plant has been limited to 1,500 h.p., to prevent complexity. Each engine is connected to its own producer, but a system of cross-pipes allows any engine to draw gas from the producer next to it, by the manipulation of the necessary valves. Since there are as many suction producers as engines the suction plants have been considered as a whole, while in the pressure plants the producers have been considered apart from the engines. At least two combinations as regard the number of units have been assumed and

the cheaper one taken. The cost of piping in the suction plants has been assumed at $3 per h.p. and in the pressure plants at $5 per h.p.

Pressure producers of the steam blower type have been chosen,

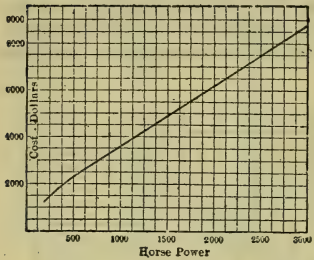


Fig. 22.

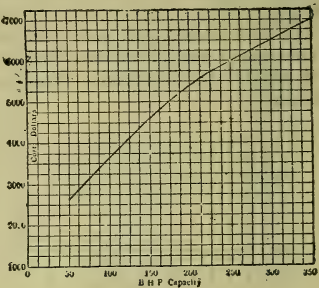


Fig. 23.

Fig. 22. Cost of gas-regulating tanks, allowing 10 cu. ft. per h.p.
Fig. 23. Cost of vertical four-cycle single-acting gas engines for direct-connecting.

therefore each pressure plant contains a steam boiler. The size of boiler necessary for a given producer was computed for the amount of steam necessary for the producer. A pressure producer uses about 0.8 lb. of steam per lb. of coal gasified; conse-

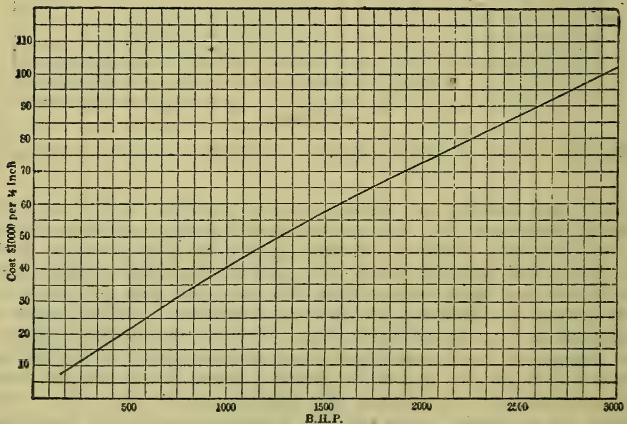


Fig. 24. Cost of horizontal gas engines for direct-connecting to generator.

quently if a producer generates one h.p. on 1½ lbs. of coal it will require 1½ × 0.8 = 1.2 lbs. of steam per h.p. This value was used therefore in computing the size of the boiler.

The cost of land for buildings, etc., was assumed at 50 cts. per sq. ft., and cost of buildings at 11 cts. per cu. ft. The size of gas-holders for pressure plants was determined by allowing 10 cu. ft. per h.p., which would be sufficient to run the entire plant for 8 or 10 mins. These holders were assumed to be placed out doors.

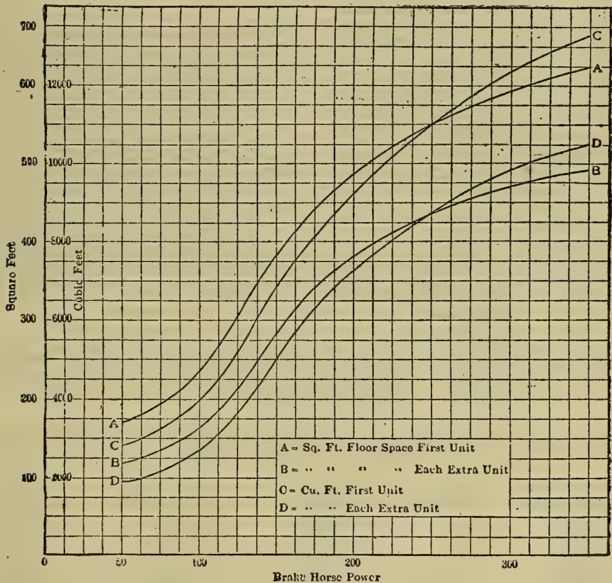


Fig. 25. Space required for suction gas producers.

In Tables XII to XV may be found the number of units chosen for each size of plant and the total cost of both suction and pressure plants complete and ready to run. The total cost includes everything found in the plant as well as the cost of the land and buildings. The number of units given in the tables for each size of plant is the number that was found to be most economical to install.

Electric Railway Gas Power Plant Costs. R. S. Manning in Power, Dec. 16, 1910, describes a large gas-driven station supplying power for an electric-railway on the Wisconsin shore of Lake Michigan. The line supplied is about 112 miles long and the service is chiefly interurban.

TABLE XII. CHOICE OF UNITS FOR SUCTION-GAS POWER PLANTS

Size of plant, brake h.p.	No. of units	Size of units	Complete initial cost of plant	Cost per rated brake h.p.
50	2	50	$12,468	$249
100	2	100	18,225	182
200	3	100	27,082	135
400	3	200	44,154	110
600	3	300	56,587	94
750	4	250	67,270	89
1,000	4	350	82,204	82

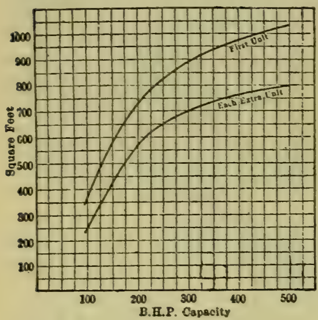


Fig. 26.

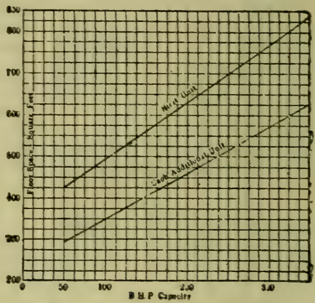


Fig. 27.

Fig. 26. Space for pressure producers, without tank or boiler.
Fig. 27. Floor space required for vertical gas engines direct connected to generator.

TABLE XIII. CHOICE OF PRESSURE PRODUCERS COMPLETE WITH AUXILIARIES

Size of plant brake h.p.	No. of units	Size of units	Initial cost of producers	Cost per rated brake h.p.
100	2	100	$8.505	$85.00
200	3	100	12.179	60.90
400	5	100	18.597	46.50
750	4	250	28.067	37.40
1,000	4	330	33.325	33.30
1,500	4	500	48.217	....
2,000	5	500	59,566	29.70
3,000	3	1,500	89,210	29.70

TABLE XIV. CHOICE OF ENGINE GENERATOR UNITS FOR PRESSURE-PRODUCER PLANTS

VERTICAL ENGINES

Size of plant, brake h.p.	No. of units	Size of units	Initial cost	Cost per brake h.p. rating of plant
100	2	100	$13,690	$136.90
200	3	100	20.370	101.80
400	3	200	32,211	80.50
750	4	250	49,061	65.40
1000	4	350	60,427	60.40
1500	6	300	82,265	54.80

HORIZONTAL ENGINES

Size of plant, brake h.p.	No. of units	Size of units	Initial cost	Cost per brake h.p. rating of plant
1000	3	500	$96,385	$96.40
1500	4	500	129,040	86.00
2000	5	500	146,195	82.10
3000	5	750	242,147	80.70

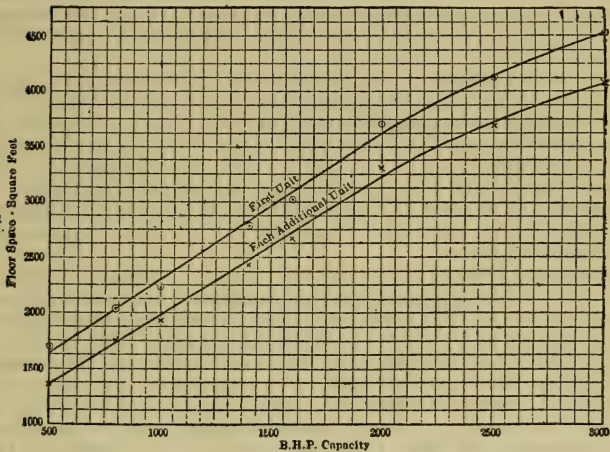


Fig. 28. Floor space required for horizontal double-acting gas engines, twin tandem type, direct-connected to generators.

TABLE XV. COSTS OF COMPLETE PLANTS, PRESSURE PRODUCERS

VERTICAL ENGINES

Size of plant brake. h.p.	Initial cost engine room	Initial cost producer	Total cost	Cost per rated brake h.p.
100	$13,690	$8,505	$22,195	$221.90
200	20,370	12,179	32,549	162.70
400	32,211	18,597	50,808	127.00
750	49,061	28,067	77,128	102.80
1,000	60,427	33,325	93,752	93.70
1,500	82,265	48,217	130,482	87.00
HORIZONTAL ENGINES				
1,000	$96,385	$33,325	$129,710	$129.00
1,500	129,040	48,217	177,257	118.00
2,000	164,195	59,566	223,761	111.80
3,000	242,147	89,210	331,357	110.40

The station equipment consists of two twin-tandem, double-acting, horizontal Allis-Chalmers gas engines supplied from Loomis-Pettibone bituminous producers and direct connected to Allis-Chalmers alternators rated at 1,000 kw. each.

Both the engines and the alternators were designed to carry large overloads and have actually carried in service 1,650 kw. for a considerable length of time.

The alternators generate three-phase currents at 25 cycles and 405 volts pressure, which is stepped up to 22,000 volts by a bank of seven 500-kw. transformers. For supplying nearby sections of the line, two 300-kw. rotary converters are used. Exciting current is furnished by two 50-kw. dynamos direct connected to three-cylinder vertical gas engines with cylinders 11 ins. in diameter and a stroke of 11 ins. The usual switchboard equipment is provided.

Two double-generator sets of down-draft producers make the gas from bituminous coal. The generators are 11 ft. in diameter and 18 ft. high, the economizer boilers are 6 ft. 6 ins. in diameter, the wet scrubbers are 9 ft. in diameter and the dry scrubbers are 12 ft. in diameter and 12 ft. high. Each double-generator set is rated at 2,000 h.p., but is capable of considerable overload.

Outside the building is a gas holder having a maximum capacity of 30,000 cu. ft., and this is provided with a 20-in. bypass pipe, with suitable valves.

The entire plant was erected by a firm of engineers whose fee was 10% of the aggregate cost of machinery, materials and construction, so that the final costs given in the accompanying table are 110% of the net costs of the installed plant

The plant was arranged for the installation of a third engine unit of the same capacity and it was estimated that the cost of this unit, including foundation, piping and electric generator, delivered and erected, will not exceed $75,000. The whole station will then have cost $396, 673.89 and have a rated capacity of 3,000 kws. The cost per kw. on rated capacity will therefore be about $132, but the cost per kw. on the maximum capacity of at least 1,650 kws. per unit or 4,950 kws. total will be about $80.

INSTALLATION COSTS

Buildings, both producer and engine:	
Material	$ 24,415.64
Labor	12,353.15
Superintendence	370.00
	$37,138.79
Engineering fee	3,713.88
Total	$40,852.67
Machinery in engine house:	
Apparatus and material	$195,421.01
Labor	2,133.45
	$197,554.46
Engineering fee	19,755.44
Total	$217,309.90

Machinery in producer house:	
Apparatus and material	$ 65,993.07
Labor	352.24
	$66,345.31
Engineering fee	6,634.53
Total	$ 72,979.84
Machinery foundations:	
Material	$ 4,680.43
Labor	3,890.16
	$8,570.59
Engineering fee	857.06
Total	$ 9,427.65
Piping complete, by contract, including labor	$ 15,654.76
Engineering fee	1,565.47
Total	$ 17,220.23
Contingent costs	5,666.91
Engineering fee	566.69
Total	$ 6,233.60
Grand total	$364,023.89
Of the above, the rotary converters, substation switchboard, substation cables, substation step-down transformers mainline step-up transformers, material and labor cost	$ 38,500.00
Engineering fee	3,850.00
Total	$ 42,350.00
Total cost of generating plant	$321,673.89

Manufacturing Plant Gas Engine and Producer Power Costs. P. R. Moses in Engineering Magazine, Dec. 1909, states that to obtain a definite idea as to comparative cost, an establishment is assumed consisting of buildings spread over several acres of ground, located close to water available for condensing purposes or other purposes. It is assumed that the heating requirements and the other uses of low-temperature heat will not amount to more than 15% of the power required for manufacturing purposes. All the machinery is electrically driven, either by group drive or individual drive. The character of the work is similar to that of a large foundry or machine shop — i. e., a heavy, more or less fluctuating, load. The plant operates 10 hrs. a day steadily throughout the year, with the exception of Sundays and holidays, and it is necessary to provide for night work, but for only a small portion of the plant.

The number of kw.-hrs. delivered per year is 1,000,000. Motors of 750 h.p. are installed and the lighting, using tungsten and other efficiency lights, amounts to 50 kws. in addition to the power load. The maximum load is figured at 400 kws. and the average load, for a 10-hr. period, at 300 kws.

The cost of the several types of plants would be, exclusive of the power house:

	Cost per k.w.
Steam equipment	$100
Gas engine and producer equipment	115
Oil engine equipment	132

The cost is subdivided as follows:

Steam:	Cost per k.w.
Compound condensing steam engine	$25
Boilers	20
Steam piping and condensers	20
Smoke stack and breeching	$4.00 to 5
Auxiliary apparatus (feed-water heater, grease extractor, steam separator)	3

If an economizer were to be installed $6.00 per kw. should be added. This would depend, of course, upon the cost of coal and the extent to which economizing might be resorted to.

Gas:	Cost per k.w.
Gas engine	$70
Producer equipment, including scrubber, etc.	15
Gas piping, exhaust heater, engine conns.	$10.00 to 15

Oil:

Oil engine	$100
Exhaust heater piping, etc.	$7 to 10

Electric (to be added to separate items in each type of plant):

Dynamos	$15 to $20
Switchboard	5 to 10
Wiring connections	5 to 10

Power House:

The cost of the power house would vary from $10 to $20 per k.w.

The prices are given per kw. of dynamo capacity, because the ratings of gas engines and turbines or steam engines are not on the same basis. The steam engine and steam turbine have overload capacities of 50% above their rated capacity, while the gas engine is rated at within 10% of full capacity, and the same is true of the oil engine. Hence, a 300-h.p. steam engine will be able to generate the full capacity of a 200-kw. dynamo, but a gas engine of the same maximum output for peak-load period should be rated at at least 400 h.p. The plant under consideration, allowing for one spare unit, for maximum load of 400 kws., could be made up of either four 135-kw. sets or three 200-kw. sets. For gas-engine or oil-engine plants, four sets would prove most economical, as the cost per kw. does not decrease as the sizes grow larger. For a steam plant, division into three or even two units would be more advisable.

The total cost of the plant would be about as follows, the steam plant being figured without superheaters or economizers:

Gas engine and producer	$70.000
Oil engine	78,000
Steam engine	60,000

The cost of operation of the three different types — i. e., the cost of fuel, labor, oil and repairs — would be:

Gas-Engine and Gas-Producer Plant:	Annual cost.
Coal, including stand-by charges, 1,000 tons at $2.50	$2,500
Labor, one machinist, one helper and one producer man	2,500
Oil	400
Repairs, averaged for a number of years	750
Total	$6,150
Fixed charges, 10% of installation cost	7,000
Total annual cost	$13,150
Oil-Engine Equipment:	
Oil at 3 cents per gal. (for fuel), 7 kw.-hr. per gal	$4,300
Labor, one machinist, one helper	1,800
Oil (for lubrication)	600
Repairs, averaged through a number of years	900
Total	$7,600
Fixed charges, 10% of installation cost	7,800
Total annual cost	$15,400
Steam-Engine Plant:	
Coal, 5 lbs. per kw.-hr. plus 20% for stand-by losses 3,000 tons at $2.00	$6,000
Labor, engineer, assistant and fireman	2,670
Oil	300
Repairs, averaged through a number of years	1,000
Total	$9,970
Fixed charges, 10% of installation cost	6,000
Total annual cost	$15,970

None of these figures includes any coal required for other purposes, and in making comparison this need not be considered unless the comparison is between a non-condensing engine and any other type of plant.

The comparative cost per kw. would be as follows:

	Cost per k.w., cts.
Gas engine and gas producer	1.31
Oil engine plant	1.54
Steam engine plant	1.59

It is evident from these figures that the gas producer and gas engine plant is about 18% more efficient than the other plants. Given equal reliability and perfection of operating results, this type of plant should have the preference, because, coincident with the reduction in cost of operation go reduction in the quantity of material to be handled, such as fuel and ashes, the absolute doing away with smoke, greater cleanliness around the plant, no steam

gaskets to blow out or packing to leak, no boiler linings to be repaired — as the producer lining lasts indefinitely, with proper care — etc.

Cost of Generating Current with Producer Gas Engines at Charlotte, N. C. Abstracted from a paper read before the American Institute of Electrical Engineers by E. D. Latta, Jr., March 30, 1910.

The engine room equipment consists of two 810-brake-h.p. horizontal twin-tandem, double-acting four-stroke cycle gas engines and one 60-h.p. single tandem exciter engine, in general similar to the large engines. The 540-kw., three-phase, 60-cycle, 2300-volt alternators, are direct and rigidly connected to the crank shafts of the main engines, and a 40-kw. direct-current generator is direct connected to the exciter engine. In addition to this apparatus there is an induction motor-driven exciter set of the same capacity as the engine exciter, a 300-kw. and a 500-kw. rotary converter, and the usual switchboard equipment.

The producer apparatus is contained in a building about one hundred feet from the power house, and consists of two 1000-h.p. units of twin generator down-draught producers, having a continuous overload capacity of 50%. Each unit consists of two 9-ft. generators, 16 ft. high, having a fuel space 7 ft. in diameter by 8 ft. high above the grate bars, which are of arched fire-clay tile. The generators are connected at the bottom by openings, lined with fire brick, containing water-cooled gate valves, to an economizer or vertical boiler of 100 h.p. rating. From the top of the boilers a 16-in. pipe leads to the bottom of the wet scrubber and from the top of the wet scrubber to the exhauster, or through a by-pass around the exhauster to the dry scrubber. A 60,000-cu. ft. holder receives the gas from the producers and delivers it to the engines.

OPERATING FIGURES FOR ONE YEAR

Engine hours	12,403
Kw. hours	3,355,907
Coal, lbs.	6,444,281
Coal per kw.-hr.	1.97
Average engine hours	34.0
Load factor	0.45

$$\text{Load factor} = \frac{\text{Output}}{\text{Engine hours} \times \text{capacity of one engine}}$$

In addition to the coal, 260,292 lbs. of coke were used in starting producers, of which amount 122,371 lbs. were reclaimed, leaving the total net amount used 137,921 lbs., equal in cost to 192,000 lbs., of coal.

We have, therefore, for the total coal consumption 6,444,281 lbs. + 192,000 = 6,636,281 lbs.

$$\frac{6,636,281}{3,355,907} = 1.97 = \text{lbs. of coal per kw.-hr.}$$

Assuming 85% efficiency for alternators at 45% load we have

$$\frac{197}{133} \times 85 = 1.275 \text{ lbs. of coal per brake h.p.-hr.}$$

Cost of Current:	Cost per kw.-hr., cts.
Coal per kw.-hr.	0.349
Power house labor per kw.-hr.	0.170
Producer labor per kw.-hr.	0.131
Oil for power house	0.065
Oil for producer	0.005
Waste and sundries, power house	0.012
Waste and sundries, producer house	0.003
Repair parts for engines	0.046
Repair parts for producers	0.007
Machine shop work, engines	0.016
Machine shop work, producers	0.007
Excelsior for producers	0.003
Water, both departments	0.071
Total cost of current at switch board per kw.-hr.	0.885

Power Consumed by Auxiliaries:	
Cooling water pump, kilowatts per kw.-hr.	0.0095
Station lighting " " "	0.0116
Motor driven exciter " " "	0.0688
Total kilowatts per kw.-hr.	0.0909

The items of interest, depreciation, taxes, etc., are not included, for the reason that they would be quite unfair to the plant, on account of the fact that it was designed for three 810 h.p. units, while only two have been installed.

Buildings, producers, gas holders, piping, etc., are all installed complete for the full ultimate capacity. Therefore a relatively small additional expenditure for one engine generator and foundation would increase the capacity of the plant by 50%, while the foregoing items of interest, depreciation, etc., would be increased but 18% per unit of capacity installed.

Costs of Power from Four Producer Gas Plants. The following data, published in The Isolated Plant Oct., 1911, were abstracted from the Journal of the American Society of Mechanical Engineers:

The plants on which the Plant Operations Committee is able to make a report are described in some detail in the following pages and following each description is a summation of their operating costs. In some instances, these cost records cover a few months and, in one instance, a considerably longer period of operation.

For the purpose of identification, but without disclosing the name or location, the plants are designed by letters.

It should be distinctly understood that the cost figures are presented as they are furnished by the operators.

Costs for Plant "A." The following are the costs and details of the plant.

Producers. There are two 250-h.p. pressure producers, 7 ft. 0 in. inside diam., with water seal bottoms and 9 in. fire-brick linings, also 2 wet scrubbers, 7 ft. 6 ins. in diam. by 18 ft. 0 in. high, filled with wooden lattice work. There are 2 dry scrubbers, 7 ft. 0 in. square by 3 ft. 6 ins. high filled with coarse shavings.

Gas Engines. There is one 500-h.p. horizontal, double-acting, 4-stroke-cycle engine with two cylinders, 23½ ins. by 33 ins., arranged tandem. The engine has three bearings rigidly in line. It runs at 150 r. p. m. and is direct connected to an electric generator. It is started by compressed air at 100 lbs. pressure and has an electric ignition of the make-and-break type, the source of supply being a 110-volt, direct-current lighting circuit and a motor generator set.

Auxiliaries. There are two tar extractors and one blower.

Details of Operation. The data received covered 2 complete months. The plant is run 24 hrs. per day from 6 a. m. Monday until 12 p. m. Saturday night, and current generated is utilized for light and power. During the 2 months, a total of 308,410 kw.-hrs. was generated and 35,190 kw.-hrs. was used in the plant, leaving a net output of 273,220 kw.-hrs.

The fuel used is bituminous coal. The cooling water from the engine is utilized for other purposes and is not, therefore, charged to the plant. The cooling and cleaning water for the scrubbers is not given.

The following was the cost of operation:

	Cost per kw.-hr.
Fuel	$0.002576
Water	0.000000
Supplies:	
Oil	0.000141
Waste, etc.	0.000024
Total	$0.000165
Superintendence	$0.000000
Labor:	
Producer room	0.001585
Engine room	0.000555
Electrical	0.000000
Total	$0.002140
Repairs:	
Producer	$0.000127
Engines	0.000040
Electrical	0.000000
Total	$0.000167
Total cost	$0.005048

Cost of Plant "B." The following are the costs and details for the plant.

Producers. There is one set of producers of the Loomis-Pettibone type.

Gas Engines. There is one 500 h.p. horizontal, double-acting, 4-stroke-cycle engine with two cylinders, 23½ by 33 ins., arranged tandem. The engine has two bearings rigidly in line. It runs at 150 r. p. m. and is direct connected to an electric generator. It is started by compressed air at 240 lbs. pressure, and has an electric ignition of the make-and-break type, the source of supply being a 110 volt lighting circuit.

Details of Operation. The data received are for 15 complete months. The plant is run 10 hrs. per day.

The following is the cost of operation:

COST OF OPERATION PER KW.-HR.

Fuel	$0.004460
Water	0.000879
Supplies:	
Oil	0.000465
Waste, etc.	0.000335
Total	$0.000800
Superintendence	$0.000000
Labor:	
Producer room	0.001603
Engine room	0.002050
Electrical	0.000000
Total	0.003653
Repairs:	
Producer	$0.000243
Engines	0.002375
Electrical	0.000000
Total	$0.002618
Total cost	$0.012410

Cost of Plant "C." The following are the costs and details for the plant.

Producers. There are two sets of producers of the Loomis-Pettibone type and of 2000 h.p. capacity each.

Gas Engines. There are two 1500 h.p. horizontal, double acting, 4-stroke-cycle engines each with four cylinders, 32 by 42 ins., arranged two in tandem. Each engine has two bearings rigidly in line. They run at 107 r.p.m. and are direct connected to electric generators. They are started by compressed air and have an electric ignition of the make-and-break type, the source of supply being a motor generator set supplying current at 60 volts.

The following is the cost of operation:

COST OF OPERATION PER KW.-HR. FOR 2 YEARS

	1909	1910
Fuel	$0.00439	$0.00422
Water	0.00000	0.00003

Supplies:		
Oil and waste	0.00029	0.00024
Miscellaneous	0.00016	0.00015
Total	$0.00045	$0.00039
Superintendence	0.00023	0.00026
Labor:		
Producer room	0.00109	0.00102
Engine room	0.00066	0.00063
Electrical	0.00000	0.00000
Total	$0.00175	$0.00165
Repairs:		
Producer	$0.00020	$0.00024
Engine	0.00006	0.00004
Electrical	0.00002	0.00005
Total	$0.00028	$0.00033
Total cost	$0.00710	$0.00688

Cost of Plant "D." The following are the costs and details for the plant.

Producers. There are two 400 h.p. pressure producers, 8 ft. 0 in. inside diameter with water seal bottoms and with 9 in. fire-brick linings, and two wet scrubbers, 8 ft. 0 in. in diameter by 20 ft. 0 in. high, filled with coke. There are two dry scrubbers, 6 ft. 0 in. square by 3 ft. 6 ins. high.

Gas Engines. There are three 250 h.p. vertical, single-acting, 4-stroke-cycle engines each with three cylinders, 20 by 19 ins., arranged side by side. Each engine has five bearings rigidly in line.

They run at 230 r.p.m. and are direct connected to electric generators. They are started by compressed air at 200 lbs. pressure and have an electric ignition of the make-and-break type, the sources of supply being a primary battery and a direct-driven magneto.

Details of Operation. The data received are for three complete months. The plant was in operation 1,439 hrs. during the 3 months and generated a total of 309,300 kw.-hrs. The fuel used was No. 1 anthracite buckwheat.

The following is the cost of operation:

	Cost of operation per kw. hr.
Fuel	$0.002828
Water	0.000000
Supplies, oil, waste, etc.	0.000572
Superintendence	0.000000
Labor:	
Producer room	0.001135
Engine room	0.002640
Electrical	0.000000
Total	$0.003775

	Cost of operation per kw. hr.
Repairs, producer	$0.00249
Repairs, engines, electrical	0.001745
Total cost	$0.008920

Cost of Coal at the plant given was $2.55 per ton at Plant "A"; $4.53 per ton at Plant "B"; unknown at Plant "C"; and $2.33 per ton at Plant "D." Reducing the cost of coal at Plant "B" to $2.50 per ton, the costs of operation compare as follows:

	Cost per kw.-hr.
Plant "A"	$0.00505
Plant "B"	0.01041
Plant "C"	0.00745
Plant "D"	0.00892
Average	$0.00796

Cost of Power Generated by 50 Brake h. p. Suction Producer-Gas Plant. J. C. Miller has given in Power, May 26, 1908, the results of the year's operation in a suction gas-power plant. The engine was of the single-cylinder horizontal hit-and-miss type, belted to a line shaft and a 50 brake h.p., drawing gas from a suction producer in which pea anthracite was used. The plant was of English manufacture, well designed, and built with ample weight to withstand all stresses. The producer was equipped with the usual vaporizing apparatus for supplying steam to the blast and the usual coke scrubber and expansion box.

Cost of plant installed	$3300
Fixed charges:	
Interest at 6%	$ 198
Depreciation, repairs, taxes, insurance, 12%	396
	$594
Operating charges:	
Engineer at $2 daily, 300 days	$ 600
67¾ tons coal at $4.50	304
Oil and waste	48
Scrubber water	12
	$964
Total yearly charge	$1558
Cost per h.p.-year of 3000 hours, assuming an average rate of 50 h.p.	$31.16

The repairs consisted of new grate-bars in the producer, new coke in the scrubber, and small repairs in the connecting-rod and ignition equipment; the total being less than ten dollars for the year.

For repairs, depreciation, insurance and taxes 12% was allowed. The cooling water was re-used so no charge was made for this item. The entire salary of the engineer was charged up to attendance although he had time for other work, not much of it being needed for the producer and engine after the plant was in

operation. The coal came from the Scranton district and cost $4.50 per ton in the bin. Brake tests of the engine were made showing over 50 h.p. and it is believed that the engine was always overloaded while working. The coal consumption averaged 441 lbs. per working day, including stand-by losses, which were low, so Mr. Miller puts the coal consumption at one lb. of coal per brake h.p.

Fuel Consumption of 75 h. p. Gas Engine and Producer. A report quoted by Professor Fernald, Bulletin 416 of U. S. Geological Survey, gave 1.05 lbs. of coal per hr. for a 10 days' test of a plant of this kind in 1909, the owner of which states that he found the operation entirely reliable. He believes that an averaged practise of the fuel would be slightly higher, but not in excess of 1.15 lbs. per h.p. hr.

Operating Costs for a Producer Gas Plant. The following costs were given in a letter to Prof. R. H. Fernald and used by him in Bulletin 55 of the Bureau of Mines:

"In January, 1907. ———— Co. installed for us a producer-gas-power plant consisting of three 50 h.p. horizontal gas engines, two of which are direct connected, making a unit of 100 h.p., and attached direct to a generator. The other engine is a separate unit with its own generator attached. We have two gas producers, one of 100-h.p. capacity and the other of 50-h.p. capacity.

"We have used this plant continuously since its installation and with satisfaction, furnishing to our plant current which is distributed throughout the works to many motors, besides furnishing light and power for one large freight and one passenger elevator.

"We do not use the full capacity of the plant, holding at all times the separate unit of 50 h.p. in reserve.

"The cost for the calendar year 1908 was as follows:

Coal	$ 538.25
Oil	49.20
Waste	11.52
Removal of ashes	18.00
Water	168.00
Gas	50.06
Attendance	581.92
Maintenance repairs	492.78
Insurance	148.68
Lamp renewals	66.70
	$2,125.11

"Our kw.-hrs. used during the entire period amounted to 134,063, making net cost to us 1.585 cts. per kw.-hr.

"Previous to the installation of the plant we employed a fireman to take care of the steam-heating plant, and our charge for attendance in the foregoing statement is the amount paid in excess of what we had previously paid for attendance on our steam-heating plant. We are obliged to keep steam up the year around, as we use it for several purposes in our factory, and the charge

under attendance, therefore, is proper but less than would follow under other conditions."

Operating Cost of a Small Producer Gas Power Plant. A. W. Honywill, Jr., gave the following data at the meeting of the American Society of Mechanical Engineers for November, 1911.

This plant drove the machinery for a wood-working shop in New Haven and the first cost of the plant, including producer, engine, blower and motor to drive it, was, in round figures, $3,500. The operating expenses per day were as follows:

Coal, 467 lbs. at $5 per ton	$1.05
Labor	2.50
Repairs and depreciation	1.16
Interest and taxes	0.70
Oil and waste	0.14
Total daily expense	$5.55

Oil engine, of the 4-cycle, hit-and-miss type, with poppet valves and jump-spark ignition, was rated at 45 h.p. and the producer was of the ordinary suction type with stationary grates, and the quantity of gas delivered to the engine being varied by a hand-adjusted throttle valve in the delivery pipe. The load was variable and the plant was in operation 9 hrs. per day, the engine being kept running during the noon hr.

The average coal consumption was approximately 467 lbs. of pea anthracite per day, or 46.7 lbs. per hr., which is equivalent to 2½ lbs. of coal per h.p.-hr., assuming an average load factor for the shop of about 40%. The cost of coal delivered was $4.50 per ton, giving an average cost per brake h.p. per hr. of 0.56 cts. No account was taken of the cost of water. The ashes from the producer were screened and the coal secured in this manner was valued at $2 per ton, reducing the actual operating expenses to $5.08 per day instead of the $5.55 in the above table.

First Cost and Annual Operating Cost of Four Small Producer Gas Power Plants. Extract from a paper by Godfrey M. S. Tait, before the National Association of Cotton Manufacturers, April 12–13, 1911.

The following are actual records of operation of small producer gas power plants:

Plant No. 1:

35 h.p. anthracite producer,
28 h.p. two cylinder engine,
18 kw. electric generator (belted),

Cost installed	$ 3,000
Interest and depreciation at 10%	300
Supplies and repairs	150
Labor per year	500
Total	$ 950
Fuel charge per kw. with coal at $4	0.30 cts.
Operating charges per kw.	0.61 cts.
Total cost per kw.-hr.	0.91 cts.

Plant No. 2 (24 hours a day service):

150 h.p. lignite producer,
150 h.p. gas engine,
100 kw. electric generator (d. c.),

Cost installed	$ 960
Interest and depreciation	960
Supplies and repairs	480
Labor per year	1,700
	$ 3,140
Cost of fuel per kw.-hr.	0.17 cts.
Cost of operation per kw.-hr.	0.43 cts.
Total cost per kw.-hr.	0.60 cts.

Plant No. 3 (24 hour a day service):

300 h.p. anthracite producer,
Two 150 h.p. gas engines,
Two 100 kw. a. c. generators operating in parallel,

Cost installed	$22,000
Interest and depreciation	2,200
Supplies and repairs	1,100
Labor per year	2,400
	$ 5,700
Cost of fuel per kw.-hr.	0.30 cts.
Cost of operation per kw.-hr.	0.40 cts.
Total cost per kw.-hr.	0.70 cts.

Plant No. 4:

400 h.p. bituminous producer (suction type, 24 hour day),
400 h.p. tandem double-acting engine,
200 ton ammonia compressor (direct connected),

Cost installed (without compressor)	$ 4,400
Interest and depreciation	4,400
Supplies and repairs	2,200
Labor (three shifts)	6,353
Fuel at 1¼ lbs. per h.p.	2,916
	$15,869

Total cost .459 cts. per hp.-hr.

This last plant was operating on Illinois slack of 10,300 B. t. u. per lb. and containing 4% sulphur and 38% volatile matter.

Annual Costs of Two 400-k. w. Producer Gas Plant Units. F. J. Rode in Mining and Engineering World, Feb. 21, 1914, states that two 400 kw. units driven by 24 by 36 in. gas engines were installed, one in 1910 and the other in 1911. The gas plant includes two producers made by R. D. Wood & Company, each of 400 h.p. rating and two producers made by the Smith Gas Power Company, rated at 350 h.p. The coal used was Hocking Valley Nut, the heat value of the gas averaging 160 B. t. u. per cu. ft.

Originally (in 1912) the plant was operated on hard coal of both buckwheat and pea sizes. By changing from anthracite to soft coal a saving in cost of operation of 0.3 ct. per kw.-hr. was effected. To change from hard to soft coal envolved installing Smith static tar extractors.

ANNUAL COST OF OPERATION

	Best month	Poorest month	Average month
Hours of plant running	568	205	333.3
Tons of coal consumed	267.7	110	187
Cost of coal consumed	$930.00	$396.00	$669.33
Cost of attendance	$767.75	$396.25	$500.54
Cost of supplies	$109.75	$26.10	$53.73
Output kw.-hr.	325,400	98,200	191,480
Cost of operation per kw.-hr.	0.556	0.836	0.634
Cost of fixed charges per kw.-hr.	0.279	0.916	0.470
Total costs cents per kw-hr.	0.835	1.752	1.104
Cost of operating including fixed charges	$2,707.50	$1,718.35	$2,122.00
Load factor during time of operation	0.715	0.60	0.71

The table gives the annual cost of operation at the plant of A. O. Smith Co., Milwaukee, Wis.

The tar is burned under steam boilers, which are used for drop forging and heating purposes, and no credit was allowed to the gas plant, although Mr. Rode explains that 9½ lbs. of water were evaporated per pound of tar burned at the boilers. The accumulation of tar varies somewhat with the volatile matter in the fuel. The coal now being used runs from 80 to 100 lbs. per ton in the Smith producers. Waste water is used for scrubbing and no charge is made in the record for the water. The waste heat of the gas engine exhaust is utilized, the boiler plant being supplied with the jacket water, which is pumped through gas engine exhaust heaters, and all the excess water is sprayed and cooled for re-use. Repair costs are included in the items of the cost of operating attendance and the cost of supplies. Mr. Rode feels that the only drawback to an otherwise eminently satisfactory equipment is the load factor, which varied to such an extent that probably better results could have obtained had it remained nearer 0.80 instead of 0.71 average.

Cost of Power by Burning Wood in Gas Producers in Mexico. E. B. Rothwell gives the following figures in Power, Nov. 9, 1909, of his experiences while in charge of gas and power plants at the Montezuma Copper Company, at Nacozari, Sonora, Mexico, in 1908.

FUEL PER H.P.-HR. AT SWITCHBOARD

	July	Aug.	Sept.
Fuel per h.p.-hr., lbs.	1.9137	1.893	2.178
Coke, lbs.	0.044	0.0356	0 0358
Oil cost per h.p.-hr.	$0.00087	0.001047	0.00085
Waste cost per h.p.-hr.	$0.000019	0.0000143	0.0000103

HORSEPOWER DEVELOPED AND GAS CONSUMPTION

	July	August	Sept.
Electrical h.p.	593.9	590.8	573
No. of days fires run	Mostly 4 days each	One 6-day and five 5-day runs	Five 5-day and one 4-day runs
Approximate average gas per min., cu. ft.	1,300	1,294	1,275

Gas Engine Costs in Electric Railway Service in England. J. R. Bibbins in Electrical Journal, Nov., 1905, states that one of the finest gas power central stations now in service in England contains 13 direct connected Westinghouse engines and eight Dowson anthracite producers, totaling 2,000 kw. capacity. It supplies light and power to the London borough district of Walthamstow and power for the borough tramways. Data from this plant covering 12 days' continuous operation show that with an average load factor of 35% the plant consumed less than 1.8 lbs. of coal per kw. hr., including fuel for all purposes. Throughout the year the coal consumption averages about 2 lbs. per kw. hr.

Table XVI shows the results of two years' operation of this plant and compares these costs with costs of similarly situated steam plants.

TABLE XVI. OPERATING COSTS — GAS POWER STATION

	1904	1903
Kw.-hrs. generated	1,019,326	659,796
Kw.-hrs. sold	814,187	542,423
Gross efficiency of system, per cent.....	80	82.25
Load factor	15.45	15.25
Operating costs	Cents per kw.-hr. generated	
Coal* and other fuel, delivered........	0.745	0.89
Oil, waste, water** and general supplies	0.306	0.37
Wages of workmen	0.590	0.67
Repairs and maintenances,† total......	0.065	0.19
Total operating cost	1,706	1.925

* Cost of coal averaged $6.50 per ton in 1902–3; $6.75 in 1903–4.
** Artesian well not yet in service; water purchased.
† Including buildings, mechanical and electrical equipments, storage batteries and distribution system.

TABLE XVII. ANNUAL OPERATING COSTS, LONDON METROPOLITAN BOROUGHS (1904)

	Average of 11 steam plants	Gas plants	Savings % favor gas
Plant capacity, kw.	2.799	810	.....
Output sold	2,997,500	1,019,326	.....
Ratio sold to generated, %....	83.9	80	.....
Load factor, %	17.25	15.45	.....
Fuel cost cts. per kw.-hr.......	1.19	0.74	+38.4
Supplies cts. per kw.-hr.	0.12	0.30	.....
Labor, cts. per kw.-h..r.......	0.43	0.48	—13.5
Repairs, cts. per kw.-hr.......	0.41	0.10	+78.0
Operating costs, total cts. per kw.-hr.	2.18	1.71	+21.5

It will be noted that Walthamstow gas plant shows a saving of 38% in fuel and 22% in operating costs. Its working costs averaged about 40% of the revenue from current.

Maintenance of Gas Engines. A 500 kw. belted gas engine plant at Bradford, Pa., gives a striking illustration of the efficiency

of gas engines when the equipment is properly operated and taken care of. The plant is in its seventh year of service; yet the repairs and cost of maintenance during the last two years have only been $92.70 per year, or 11.6 cts. per h.p. year. Table XVIII shows the complete operating cost of this plant for the last two years, averaging eight and one-half mills per kw.-hr. on a load factor of less than 20%, and this with antiquated electrical apparatus.

TABLE XVIII. OPERATING COSTS 500 H.P. GAS POWER STATION, BRADFORD, PA.

	1904	1903
Annual output, kw.-hr.	804,092	780,300*
Station load factor, %	19.54	......
Gas consumption, cu. ft.	20,056,000	18,162.000
Plant duty (including heating) cu. ft., per kw.-hr.	24.9	22.4
Average price of gas, cts. per 1000 cu. ft.	12.32	16.5
Operating costs	Cents per kw.-hr. generated	
Fuel (including heating)	0.307	0.384
Labor, power station only	0.380	0.392
Supplies	0.059	0.072
Repairs, engine and electrical equipment	0.079	0.050
Repairs, gas engines only	0.010	0.013
Total works or operating costs	0.825	0.898

* Estimated from 9 months' metered output.

Cost of Power in a Small Plant Using Illuminating Gas for Operating Gas Engine. This plant carries a motor load of about 40 h.p., and about 200 incandescent lamps for lighting, the motors driving various lathes, drill presses, buffing wheels, etc., for the manufacturing of band instruments. The outfit consists of a Crocker-Wheeler 220 volt d.-c. dynamo of 25 kw. rated capacity driven by a 40 hp. Nash gas engine.

FUEL CONSUMPTION AND ELECTRICAL OUTPUT FOR NOVEMBER, 1911

Gas consumed, cu. ft.	121,100
Output, kw.-hr.	4,542
Fuel cost per kw.-hr., cts.	2.13

The engine is of the 2-cylinder, 4-stroke type, equipped with a throttling governor, and running at 275 r.p.m., ignition current being supplied from a small storage battery charged by a special igniter generator, mounted on the frame of the engine and driven by a belt from the main shaft. Fuel is illuminating gas. The engine starts by compressed air at 180 lbs. pressure, stored in two small steel tanks, by a small motor single-cylinder vertical compressor. Cooling water, after passing through the cylinder jackets, is run through a transverse-current water heater, which utilizes the heat of the engine exhaust to raise the temperature

of some 200 gals. of water per hour from about 140 to 180 degs. F.

Besides looking after the generating equipment, the engineer runs the heating plant and takes care of all the motors, shafting, wiring, piping, plumbing, etc., throughout the building. In estimating the cost of power, 25% of his salary of $100 per month is prorated of this item. The cost of water is not charged against the engine as all of it is used throughout the factory. The average consumption of lubricating oil is 0.9 gal. per day at 36 cts. per gal. There were no charges against the power equipment for one year after installation.

Cost of Plant and Power. The cost of the plant with all accessories and complete was as follows:

25 kw. unit (installed 1911) $3250, equals $130 per kw.
15 kw. unit (installed 1907). $1775, or $118 per kw.

A. R. Maujer published the above figures in Power, July 2, 1912, and states that the following is a fairly accurate estimate for the cost of power for November, 1911.

Fuel (121,100 cu. ft. of gas at 80 cts. per 1000 cu. ft.)	$96.88
Labor (25% of engineer's time)	25.00
Oil	8.10
Interest, depreciation, etc. (12% per annum on $5025).	50.25
	$180.23

$$\text{Cost per kw.-hr.} = \frac{\$180.23}{4542} = 3.97 \text{ cts.}$$

Amount of Power Available from Furnaces. A rule for estimating the amount of power available for external use from gases generated at blast furnaces and by-product coke ovens is gven by L. Greiner in 1907:

With blast furnaces, the continuous available h.p. is equal to the number of tons of iron made per month.

With by-product recovery ovens, the continuously available h.p. is equal to the number of tons of coke made per week.

Operating Costs of Small Gas Engine Plant for Electric Light Service at Minster, Ohio. The following data are from the records of the Municipal Electric Light Plant reported by M. W. Utz in Power, Feb. 18, 1913.

The plant comprises two 3-cylinder vertical 4-stroke-cycle gas engines of 12 by 12 ins. and 11 by 12 ins. respectively, direct connected with 62.5 and 50 kw., 250 volt d. c. generators. Both engines have make-and-break ignition, the first being supplied by a magneto bolted to the engine frame and driven by a friction pulley from the flywheel; the other is supplied by a ¼ kw. generator belted to the engine shaft. Both are equipped with batteries for starting or for use in case of a breakdown of the magneto or generator.

On a typical day the gas consumption was 10,725 cu. ft. per hr. and the output was 723 kw.-hrs. The average gas consump-

tion per kw.-hr. was therefore 14.8 cu. ft. The average amount of oil consumed was 4 gals. per kw.-hr.

In a typical month (April, 1912) the gas consumption was 283,250 cu. ft. and the output was 17,608 kw.-hrs. The average fuel cost for the month was 0.048 cts. per kw.-hr.

In this month the total operating and overhead costs were as follows:

283,250 cu. ft. of gas at 30 cts. per 1,000 cu. ft.	$84.97
2 engineers at $55 each	110.00
120 gal. at 19 cts. per gal.	22.80
Interest, depreciation, etc., 15% per annum on $9,000	112.50
	$330.27

The total cost per kw.-hr. was therefore 1.87 cts.

Cost of Diesel Engine Operation in England. Chas. Day in Power, Oct. 3, 1911, gives figures published in the Electrical Times covering practically almost all the supply stations in Great Britain, and from this information combined with information obtained direct from station engineers the author determined the average results obtained in such stations.

TABLE XIX. COST PER KW.-HR. SOLD

Type of engine	Fuel, cts.	Lubricating oil, waste, stores, and water, cts.	Wages, cts.	Repairs and maintenance, cts.	Total oper- costs, cts.	Load factor
Steam	0.90	0.12	0.50	0.52	2.04	14.7
Gas	.86	.18	.56	.48	2.08	15.3
Diesel	.46	.08	.38	.14	1.06	14.3

The limit of 1000 h.p. was fixed owing to there being as yet no large electricity-supply stations equipped solely with Diesel engine or gas engines. Of course, better results are obtained with driving machinery which gives a better load factor, but the causes which produce loss are, as a rule, the same, though modified in extent. The general conclusion formed from a study of electricity stations holds good for the great majority of power users, though perhaps not applicable to some special trades, where engines can be run continuously on almost uniform loads. It is also necessary to point out that the figures include some items which should not strictly be charged against the power plant. For instance, the wages items include figures for men working on cables, street lamps, and in substations, and the repair items include repairs to such parts. Also it is necessary to mention that the figures give the costs per unit of energy sold, not per unit generated.

From the averages it is clear that a substantial gain is obtained by the adoption of Diesel engines as against either gas or steam engines, the figures being beyond doubt substantially accurate. It is also noticeable that the gain is not only on fuel consumption, but is practically in the same proportion on the other items of expenditure.

The great saving shown by these average figures is confirmed by repeated experiences of the author. In many cases, although the figures guaranteed with Diesel engines have been no better than figures previously guaranteed and obtained on tests, with existing steam and gas engines, the Diesel engines have shown over extended periods a saving of 50 and 60%, and in some cases an even greater percentage, the result being due to the fact that the Diesel engine's average working results were very much nearer to the guaranteed figures than with gas or steam engines, combined with the fact that the relatively high cost of working at light loads with gas or steam had not been sufficiently taken into account when considering the guaranteed figures.

When going through cost records to prepare the average figures previously given, the author noticed very wide differences of cost per unit, particularly in the case of the steam plant. He therefore had the average cost calculated for steam stations of different capacity, and as the results are interesting, they are given separately in Table XX.

TABLE XX. OPERATING COST PER KW.-HR. SOLD, FOR STEAM STATIONS OF DIFFERENT SIZES

Station capacity, kw.	Fuel, cts.	Lubricating oil, waste, water and stores, cts.	Wages, cts.	Repairs and maintenance, cts.	Total cts.	Load factor
250	1.26	0.18	0.70	0.72	2.86	13.2
500	1.12	.12	.54	.58	2.36	13.3
750	.86	.10	.46	.48	1.90	15.4
1,000	.80	.10	.46	.42	1.78	16.8
1,500	.84	.08	.34	.36	1.62	16.9
2,000	.74	.08	.32	.42	1.56	17.7
3,000	.66	.08	.30	.34	1.38	17.4
4,000	.80	.06	.28	.40	1.54	18.8
5,000	.68	.06	.22	.32	1.38	18.7
7,000	.72	.08	.26	.40	1.46	17.9
10,000	.52	.06	.18	.26	1.12	22.6
20,000	.60	.06	.22	.32	1.20	19.6
50,000	.46	.04	.20	.22	0.92	20.56

It is to be noted that, even with the largest steam stations, the costs per unit generated are no better than for quite small stations using Diesel engines, and this in face of the improved load factor. This is a most important point, and shows that small Diesel stations can profitably supply current at prices hitherto thought to be obtainable only in densely populated centers having large power stations.

In all cases the figures which have been given are operating costs and do not include anything for interest on capital or depreciation. It is hardly possible to give a definite statement showing the cost of constructing and equipping power houses of different types, as there are so many variable factors. However, the author's experience of a considerable number of estimates indicates that up to a capacity of, say, 1000 kws., there is gen-

erally little difference between the gross capital expenditure required, whether steam, gas, or Diesel engines be adopted.

Oil-Engine Costs and Operating Expenses for Different Types in Small Plants. A. H. Goldingham and W. H. Adams presented the following table and diagrams at the Panama Pacific Exposition meeting of the A. S. M. E. and Electrical World, Oct. 9, 1915, gives a reprint of their article.

TABLE XXI. APPROXIMATE COST OF OIL ENGINES PER BRAKE H.P. AND FUEL DATA

Type of engine	Specific gravity of oil (deg. Baume)	Approximate price of oil per gal., cts.	Thermal efficiency at full load	Brake hp.-hr. per gal. of fuel	Approximate cost of engines per brake-h.p. Horsepower			
					50	100	150	250
Distillates	48–51	5	20	10	$25	$30	$30	$30
Tops-distillates	38–42	2.75	20	10	25	30	30	30
Semi-Diesel ...	24–28	2.14	18	10	60	55	50	50
Hot-surface high efficiency ...	16	2.14	27	16	..	65	65	60
Diesel	18	2.14	28.4	16	75	75	70	65

The curves are based on interest at 6%, taxes and insurance 1%, repairs 3%, depreciation 10% and fuels and cost of engines at prices given in Table No. XXI, allowance being made for labor.

The horizontal lines have been added to each set of curves to facilitate estimating the total operating cost when the average load on a machine is less than the rated full load. To make such an estimate the procedure is as follows: Measure the ordinate corresponding to the hours the machine is operated between the inclined and horizontal line for the particular engine and by laying off an equal distance on the scale at the left obtain the number of dollars representing the cost fuel which would be required with the engine operating at full load. Then multiply this amount by the average percentage of rated load carried and also by the ratio of the fuel economy at the particular load to the economy at full load. By adding the result so obtained to the ordinate of the fixed-charge line the approximate yearly operating cost at that average load will be obtained.

This arrangement of curves also permits a comparison of fuel costs for different engines and periods of operation. It is interesting to note that 50-h.p. tops distillates engines are cheaper to operate than any of the other types of the same rating up to

7200 hrs. a year. In 100 h.p. sizes hot-surface, high economy engines are cheapest to operate when used more than 5000 hrs. a year. Below this tops-distillates engines show an advantage. With higher rated engines tops-distillates and hot surface, high-economy engines remain the least expensive to operate, the point

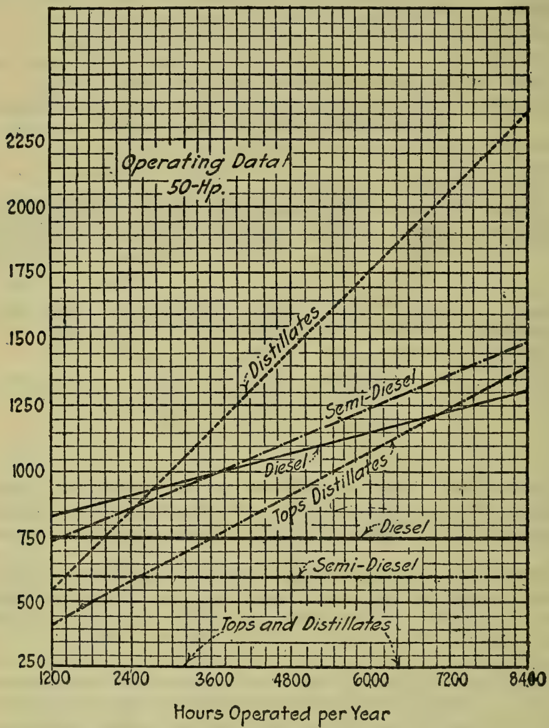


Fig. 29. Annual cost of operating 50-h.p. oil engine at full load. Horizontal lines indicate the fixed charges.

at which it is best to change from one to another changing with the rating needed. In practically all cases it can be seen that distillates engines are practically out of the question because of their high cost of operation.

Cost of Diesel Engine Power for a Textile Factory. R. S. Streeter in Engineering Magazine describes a Diesel engine at the MacLaren Knitting Company's mill at West Sand Lake, New

York, installed in April, 1910, and used to run knitting machinery.

The air compressor is belted to the main shaft of the engine and is placed so that the same belt can be used to drive the compressor from the line shaft and in this way pump up the air pressure with the water wheel when it is necessary.

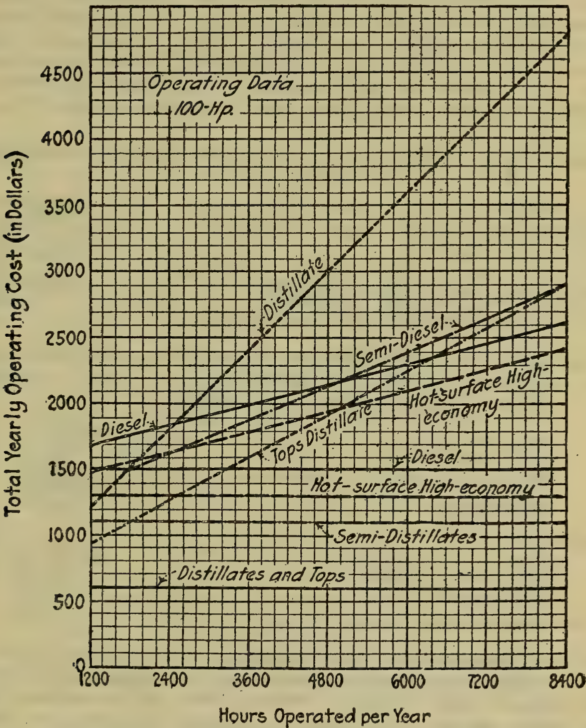


Fig. 30. Annual cost of operating 100 h.p. oil engines at full load. Horizontal lines indicate the fixed charges.

The fuel used in this engine is a heavy fuel oil and is transported by horse and wagon from Albany, N. Y., a distance of 9 miles. The oil costs about 5 cts. a gal. delivered at the engine room, but if it were possible to get it in tank cars it could be had for 3 cts. a gal.

This engine on the 8-hr. acceptance test at full load or at an average h.p. of 75.8, showed an oil consumption of .512 lb. per brake h.p.-hr. The 2-hr. acceptance test at three-quarter load showed a consumption of .515 lbs. per brake h.p., the one-half-load consumption was .612 lbs. and the one-quarter-load .890 lbs. per brake h.p.-hr.

There is a central station at Westerly, R. I., which contains four Diesel three-cylinder 16 by 24-in. engines running at 164 r.p.m. This station supplies electricity for lighting and for small motors for Westerly, Richmond, Ashaway, Watch Hill, Stonington, Pawcatuck, Mystic, and Noank, which towns have a population of about 25,000. The maximum load on the station is 640 kws. For a period of eight months ending August 31, 1909, the operating expenses of the plant were as shown in Table XXII.

TABLE XXII. OPERATING COSTS, DIESEL-ENGINE DRIVEN CENTRAL STATION

Total kw.-hrs.	1,233,590
Energy for compressors, pumps and exciters	312,880
Total energy for distribution	920,710
Gals. fuel oil	115,708
" " " per available kw.-hr.	0.12
Cost fuel oil, lubricating oil and water	$3,632.22
Cost fuel oil, per kw.-hr. available	$0.0039
Cost of generating energy per available kw.-hr.	$.009

The above figures include fuel oil, lubricating oil, water, labor and maintenance but do not include interest, taxes or depreciation. The analysis of the cost is as follows:

Fuel oil	$3,356.10
Lubricating oil	236.75
Water	39.37
Labor	3,685.43
Miscellaneous	68.52
Maintenance:	
Engines and compressors	$ 905.34*
Electrical equipment	58.96
Miscellaneous	25.15

* Includes general yearly overhauling.

In the Bellefontaine, Ohio, municipal electric plant there are two 225 h.p. Diesel engines, each direct connected to a 150-kw. 2,300-volt 60-cycle generator. It has been the experience there that these engines work well in parallel operation. At three-quarters load these engines use 9.75 gals. of crude oil per 100 kw. hr. generated. For the three years from May, 1906, to May, 1909, the average load factor on this plant was 46.7%. The cost per kw.-hr. was, for that time, $0.0062. This included fuel, lubricating oil, repairs and attendance.

Cost of Power by Diesel Engine, Using Retort Tar as Fuel, was described by W. Allner, Jour. für Gashel, Apr. 8, 1911, and reprinted by Progressive Age, June 1, 1911.

Tests on a 100 h.p. Diesel engine made by Körting Co., were made using an auxiliary fuel in the shape of paraffin oil. Tar and paraffin oil are conveyed to the nozzle by 2 separate small pumps, which are driven by the engine. The engine is direct coupled with a direct current dynamo and works in parallel with

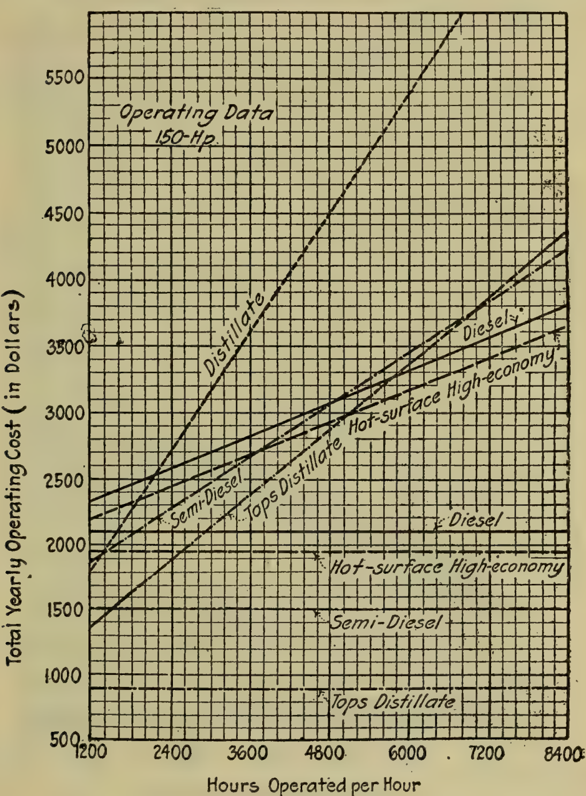


Fig. 31. Annual cost of operating oil engines of 150 h.p. at full load. Horizontal lines indicate fixed charges.

a number of suction gas engines on the power and lighting supply of the factory. The tests were made at full, ¾ and ½ load. The fuel supply was weighed and tested. The engine is arranged so that the supply of ignition oil varies with the load. The relation between paraffin oil and tar can also be varied. The engine

has also a change gear, which permits changing the tar pump to paraffin oil, so that in starting, the engine can work with paraffin oil till the engine is in a satisfactory, warm condition for the tar fuel. The tests prove that the total consumption of heat of the engine when fed with tar and ignition oil is with all loads as great

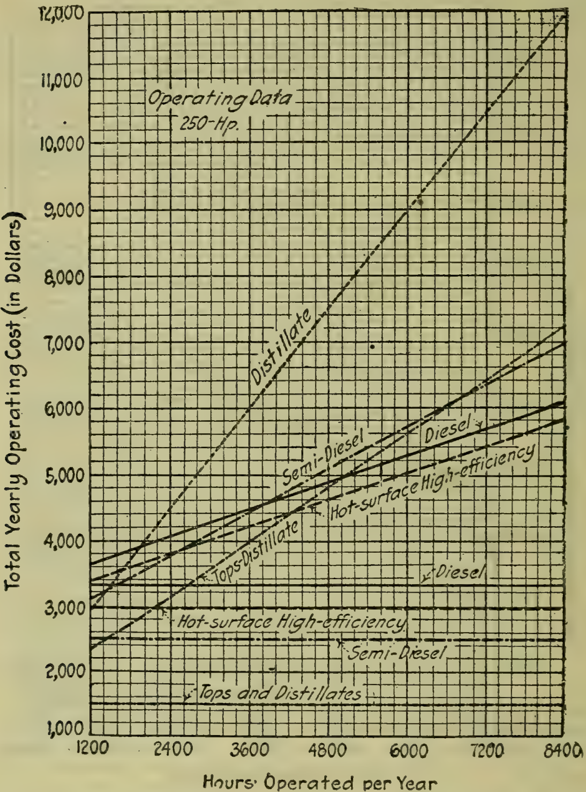


Fig. 32. Annual cost of operating oil engines of 250 h.p. at full load.

as when driven with pure paraffin oil. The consumption of ignition oil, moreover, is very small. On the average it is:

With full load, 2%.
With ¾ load, 7.5%.
With ½ load, 13%.

With full load the ignition oil could have been omitted with safety, although it is advisable to allow this pump to work constantly so as to have it always in working order. The following results were obtained in regard to fuel consumption, with a 100 h.p. Diesel engine, requiring about 1,850 cal. (4,306 B. t. u.) per

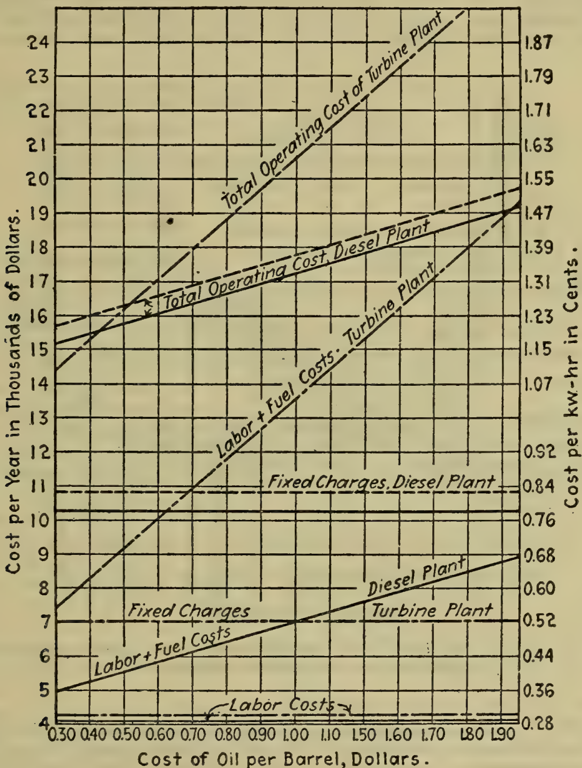


Fig. 33. Comparison of operating expenses of 600-kw. steam turbine and Diesel-Engine plants.

h.p.-hr. With full load per h.p.-hr., 63 ozs. tar and 0.1 oz. paraffin oil. With ¾ load per h.p.-hr., 60 ozs. tar and 0.5 oz. paraffin oil. With ½ load per h.p.-hr., 57 ozs. tar and 0.7 oz. paraffin oil. The net calorific power of the paraffin oil is taken as 10,000 cals. (39,683 B. t. u.); that of tar as 8,500 cals. (33,730 B. t. u.) per 2.2 lbs. The engine was fed with vertical re-

tort tar from more than six gas plants, so that the matter of tar composition in the fuel is out of the question. After the 66-hr.-test the engine was stopped, and valves, combustion chamber and all inner parts thoroughly examined. It was found that the engine had no residues, that no deposit had formed, and that the entire operation had been almost smokeless. The engine was also subjected to severe conditions, as, for example, changing suddenly from full load to half load. Here also

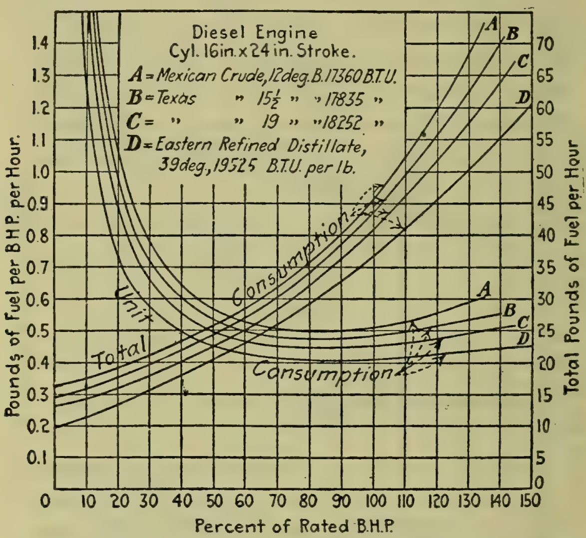


Fig. 34. Unit and total fuel consumptions for Diesel Engines at different percentages of rated load.

the results were satisfactory. Further arrangements were made to test horizontal retort tar. But no definite results have yet been established. An ordinary Dessau vertical retort uses about 22,000 lbs. coal per day, and yields about 1,100 lbs. tar, which would be sufficient to run a 200 h.p. engine for 12 hrs. per day with full load. If we estimate the tar at $7.50 per 2,200 lbs., we get operating costs.

Consumption of tar per h.p.-hr. for medium-size engine....	0.16 cts.
Consumption of ignition oil per h.p.-hr. at a cost of 22 cts. per 2,200 lbs.	0.01 cts.
Total cost of fuel	0.17 cts.

With use of pure paraffin oil about 5.5 ozs. per h.p.-hr. would be needed. With a 100 h.p. engine and 3,000 working hours per year, this would be:

Cost of tar	$480
Cost of ignition oil	23
Cost of ignition oil to start engine	30
Total cost with tar	$533

Oppose to this paraffin oil drive, which would cost $1,178, and tar oil fuel, with the lowest

Cost of $9.50 per 2,200 lbs.	$599
Cost for ignition oil	23
Cost for ignition oil to start engine	30
	$652

This shows that tar fuel is the least expensive for Diesel engine fuel. The necessary change in the construction of the engine is only about 5% of the original cost, and this is soon balanced by the greater saving in fuel cost.

Costs of Power for Two American 225 h. p. Diesel Engines, with triple 16 by 24 in. cylinders, direct-connected to alternators running 164 r. p. m. were given in Power and The Engineer, Jan. 26, 1909, as follows:

The total cost of the station was about $105,000, or $234 per h.p. of normal rating. The manufacturing cost in the plant was made up of the following items: Fuel oil, $3400; water, $88; oil and waste, $347; wages, $3613; station repairs, $5; oil-plant repairs, $663; electric-plant repairs, $13; total, $8129. The energy delivered at the switchboard was 817,000 kw.-hrs. The operating cost was thus about 1 cent per kw.-hr. The total cost of the power, however, included the interest on the initial cost of the plant, assumed as 6%; depreciation, taken at 7%; taxes, 1%; insurance 1%; total fixed charges, 15%. The plant cost was made up of: Building, $39,288; real estate, $17,957; oil plant, $38,500 ($85.50 per h.p.); electric plant, $9500. The total fixed charges were, therefore, 15% of $105,000, or about $15,700 per year. The manufacturing cost at the station per kw.-hr. figures about half the fixed charges per kw.-hr., the latter coming to about 1.92 cts. Thus the total cost of producing power in this plant is not far from 2.92 cts. per unit generated.

Cost of Operating Two Oil Engine Plants. The following data on cost of operation of oil engines were abstracted from The Isolated Plant, June, 1909:

The Baldwin Locomotive Works, Eddyston, Pa., has operated for 4 years ten 125-h.p. Hornsby-Akroyd oil engines (manufactured by De La Vergne Machine Co., New York). Six are direct connected to direct current generators and 4 are coupled to air compressors. These engines operate regularly 24 hrs. per day, 6 days and often 7 days per week.

We are indebted to C. K. Goodell, superintendent of motive power, for the following output figures for the year of 1908:

Kilowatt hours at switchboard	997,124
Electrical h.p.-hrs. (equivalent to above)	1,336,622
Compressor output at receivers (computed)	482,375
Total output at switchboard and receivers	1,818,997
Equivalent brake h.p.-hrs. assuming the efficiency of generators and compressors at 85%	2,139,996
Load factor, compared with full load	24%

Cost of above power:

Fuel oil	$7,894.79
Lubricating oil waste and supplies	1,196.40
Repairs	1,320.00
Wages for attendance	3,615.82
Total cost exclusive of fixed charges	$14,021.01

While the guaranteed oil consumption for these engines per brake h.p.-hr. was one lb. at three-quarters to full load, carefully conducted tests showed the consumption at full load to be as low as 0.66 lb. per brake h.p.-hr.

The above figures apply to the whole power plant. If we assume the engines to be chargeable with 80% of the lubricating oil and repairs we can arrive at two important figures:

	Cts.
Lubricating oil, per 1,000 b. h.p.-hrs.	56
Repairs, per 1,000 b. h.p. hrs.	62

The wages for attendance for the entire power plant were less than 50 cts. per hr. This brings out strongly the low attendance cost of the oil engine. The cost per electrical h.p.-hr., exclusive of fixed charges, was 0.77 ct. Cost per brake h.p.-hr., 0.66 ct.

Assuming cost of plant at $120,000 fixed charges for interest and depreciation at 11% = $13,200.

This brings the total cost of power up to $27,221. Cost per brake h.p.-hr. including fixed charges was 1.27 cts. Cost per kw.-hr. including fixed charges was 2 cts.

These two figures are not representative, as during 1908 the plant was running greatly below normal. The load factor was 24%. Under conditions other than those existing in a panic year, the load factor would be at least 60%, and this would make the cost per brake h.p.-hr. 0.8 ct. and per kw.-hr. 1.26 cts.

Mr. Goodell informed the writer that in the 4 years the engines had been in operation, they have not yet "ground in" a valve. He considers the oil engines to be fully as reliable as a steam equipment would be. Overloads up to 25% have been carried successfully.

The Atlantic Hotel & Supply Co., 676 Hudson Street, New York, have one 35 h.p. Hornsby-Akroyd oil engine, belt connected to a 15-ton refrigerating machine and circulating pump. We are indebted to Mr. Colter, the engineer of the plant, for the following figures:

Average load (determined from indicator assuming mechanical efficiency from previous tests), 25 h.p., which is practically constant.

Fuel and lubricating oil consumption for one year and the power output is given below:

Fuel oil, gals.	14,988
Cylinder oil, gals.	185
Engine oil, gals.	91
Hours operated	6,024
Average hours per day	16.5
Lbs. fuel oil per brake h.p.-hr.	0.75

COST OF POWER

Fuel oil, 14,988 gals. at 4¼ cts. (tank wagon lots)	$ 637.00
Cylinder oil, 185 gals. at 50 cts.	92.50
Engine oil, 91 gals. at 35 cts.	31.85
Waste and supplies, about	15.00
Total for oil and supplies	$ 776.35
Attendance, about $2 per day, should be charged	730.00
Fixed charges, 12½% on about $2,500	312.00
	$1,818.35
Total output, 6,024 hrs. × 25 h.p. = 150,600 brake h.p.-hrs.	
Cost per brake h.p.-hr.	1.2 cts.
Guaranteed oil consumption, three-quarters to full load per brake h.p.-hr.	1 lb.
Actual oil consumption per brake h.p.-hr.	0.75 lbs.
Actual cost of lubricating oil per 1,000 brake h.p.-hrs.	83 cts.

NOTE.— It is questionable what attendance charge should be made, for the same wages would be paid whether the plant were operated by an oil engine or by a motor, but in the latter case the attendant would have more spare time. The repairs to this plant during the 3 years it has been running are practically negligible. One continuous run of 820 hrs. was made recently. The engine has been absolutely reliable.

Cost of Power with Diesel Oil Engine. Plant of the Prairie Pebble Phosphate Co., Mulberry, Fla., April, 1911. Rated capacity was 2,400 kws. The costs are for one week.

Total kilowatt-hours	294,600
Fuel oil, gallons	24,528
Fuel oil, gallons per 100 kw.-hrs.	8.33
Engine oil, gallons	447
Dynamo oil, gallons	1¾

	Cost for 7 days
Cost of fuel oil	$525.60
Cost of lubricating oils	121.51
Supplies and repairs	44.32
Operating labor	335.25
Total weekly expense	$1,026.68
Aggregate kilowatt-hours for 4 weeks	1,169,800
Aggregate expenses for 4 weeks	$4,123.25
Cost of operation per kw.-hr., average	3.525 mills

Performance of Diesel-Engine Plants in Texas. R. H. Burdick in Electrical World, March 11, 1916, describes eight Diesel-engine

installations in small electrical generating stations in Texas operated by the Texas Power & Light Company. Tests have been conducted at these plants and operating records kept which show results of performance and operating practice in modern plants of this type. In what follows data are presented in considerable detail, giving performance for a recent installation at Paris, Tex.

The Paris installation consists of an initial equipment of three McIntosh & Seymour Diesel engines rated at 500 h.p. each. These units are of the four-cylinder, four-stroke-cycle design operating at 164 r.p.m. and directly connected to three 437-kva., 2300-volt, three-phase, sixty-cycle alternators. Two 35-kw. induction motor-driven sets and one 35-kw. belt-driven exciter set are provided, the latter being driven from the generating unit. Compressors and water-circulating pumps are integral with engines.

TABLE XXIII. DIESEL-ENGINE STATIONS OPERATED BY TEXAS POWER & LIGHT COMPANY

Location	Number of units	Total h.p.
Paris	3 of 500 h.p. each	1,500
Palestine	1 of 500 h.p.	500
Tyler	4 of 225 h.p. each	900
Taylor	1 of 225 h.p.	225
Brownwood	3 of 225 h.p. each	675
Gainesville	3 of 225 h.p. each	675
Sweetwater	2 of 225 h.p. each 1 of 170 h.p.	620
Big Springs	2 of 225 h.p. each	450
Total	20 averaging 277 h.p. each	5,545

NOTE.— McIntosh & Seymour engines are used at Paris and Palestine, Busch-Sulzer in all other stations.

The approximate cost of another representative Diesel station erected by the Texas Power & Light Company in the latter part of 1914 at Tyler, Tex., is given in Table XXV. This plant includes an initial installation of two second-hand Busch-Sulzer Diesel-engine sets built in 1907–1909, each consisting of two three-cylinder, four-stroke-cycle, 225-h.p. engines directly connected to one 300-kw., 164 r.p.m. three-phase, sixty-cycle, 2300-volt generator. One 17-kw. induction motor-driven exciter set and one 20-kw. exciter belt-driven set operated from one of the engines were also provided. The necessary auxiliaries such as air compressors, water and oil pump, cooling tower and the like were included. The apparatus at this station is housed in a steel-frame plastered building 74 ft. 5 ins. by 48 ft. by 21 ft. 6 ins. to bottom truss and similar in construction to the Paris plant building. The feeder arrangement at this station provides service at 2200-volt, three-phase alternating current for power and lighting; 550-volt to 250-volt d.-c. power, and 550-volt d.-c. for railway service. An oil-storage tank of 360 barrels capacity and a cooling tower of the atmospheric type containing 4700 sq. ft. of cooling surface are provided.

TABLE XXIV. ACTUAL UNIT PRODUCTION COSTS, PARIS AND TYLER DIESEL STATIONS, SEPT. 1 TO DEC. 31, 1915

	Paris	Tyler
Station output (m. kw.-hr.)	1,565	499
Rating of plant (kw.)	1,050	600
Station factor, %	51	28½
Total fuel oil (gal.)	149,072	78,455
Pounds oil per kw.-hr. output	0.672	1.100
B.t.u. per kw.-hr. output	13,100	21,400
Production costs (mills per kw.-hr.):		
All labor	1.44	2.24
Fuel oil	3.07	5.18
Water	0.09	0.19
Lubricants and waste	0.04	0.56
Miscellaneous supplies and expense	0.10	0.29
Maintenance of engines	0.04	4.48
Maintenance of buildings	0.05	0.05
All other maintenance	0.15	0.61
Total production cost, mills	4.98	13.60

TABLE XXV. APPROXIMATE COST OF TYLER DIESEL STATION

Article	Quantity	Unit cost	Cost per kw.	Per cent. of total	Total
Station building, cu. ft.	100,000	$0.111	$18.50	12.6	$11,146
Engine and generator equipment, e.-h.p.	900	50.00	74.95	51.1	44,968
Electrical equipment, kw.	600	$13.90	13.90	9.5	8,340
General station equipment for entire job	...	....	8.64	5.9	5,185
Improvements to grounds	...	....	0.67	0.5	400
Construction plant % of cost	$70,039	2%	2.34	1.6	1,400
Overhead expenses* % of cost	$71,439	23.2	27.60	18.8	16,561
Total cost, kw.	600	$146.66	....	...	.....
Total cost, e.-h.p.	900	$97.78	....	100	$88,000

* Overhead expenses consist of the following cumulative percentages: (A) General expense, 5%; (B) contingencies, 5%; (C) engineering, 10%; (D) interest during construction, 1.5%.

Labor Item in Diesel-Engine Plants. The question of labor has frequently been considered the "bugbear" of Diesel-engine operation. It has been the writer's experience, however, that any careful mechanic well versed in the theory of internal-combustion-engine operation can handle any Diesel engine satisfactorily with a minimum of difficulty.

At the Paris plant the force consisted of 1 engineer at $150 per month, one assistant engineer at $85, two assistant engineers at $75, one oiler at $60 and one switchboard attendant $75. All were white men. At Tyler there were two white engineers at $85 and $75 and two colored assistant engineers at $45.

Engine Maintenance. The wide diversity of maintenance costs between the stations is accounted for by the facts that the Paris engines are of more modern design than the Tyler engines, the

former having been operated but eight months, while the latter have done miscellaneous severe intermittent shop duty over a period of six to seven years prior to the installation at Tyler, and that during the period covered the Tyler equipment was subjected to certain extensive repairs and overhauling as a result of neglect prior to and at the time of its first trial in central-station service.

In this connection it will be of interest to note that upon close investigation of numerous accidents to Diesel engines practically all of them have been traceable to one or two causes — the neglect of mechanical features and faulty mechanical design. The chief cause of troubles seems to have been the former, which is the direct outcome of carelessness on the part of operators and which if practiced in the operation of steam or other type of equipment would have been fully as serious.

The length of life of the Diesel-engine parts has been estimated by those familiar with their operation as follows: Bed and frame, 20 years; crank shaft and governor, 10 years; cylinder linings, 6 years; wrist-pin brasses, 5 years; cylinder heads, 4 years; pistons, piston pins, valves and gears, 3 years; piston rings, 1 year.

Summarized, this information shows a life equivalent to 20 years with one-third of the original cost expended on maintenance during that period, which estimate may be considered conservative.

Operating Expenses of a Hot-Surface Oil Engine Plant in New Mexico. The following is from papers read by A. H. Goldingham

TABLE XXVI. OPERATING EXPENSES IN A NEW MEXICO HOT-SURFACE OIL ENGINE PLANT

Estimated output at switchboard, kw-hr.	2,469,293
Estimated output at engine, h.p.-hr.	3,996,196
Oil consumed, gals.	278,595
Oil consumed, lbs.	2,061,602
Oil consumed, gal., per kw.-hr. switchboard	0.113
Oil consumed gal., per h.p.-hr. engine	0.083
Labor cost operating	$7,907.31
Labor cost operating per kw.-hr.	0.0032
Labor cost operating per h.p.-hr.	0.0019
Labor cost maintenance	$2,211.76
Labor cost maintenance, per kw.-hr.	0.0009
Labor cost maintenance per h.p.-hr.	0.0006
Cost of fuel oil at 16.5 cts. per gal.	$46,603.62
Cost of fuel oil at 16.5 cts. per gal. per kw.-hr.	0.0189
Cost of fuel oil at 16.5 cts. per gal. per h.p.-hr.	0.0116
Cost of lubricating oil at 71 cts. per 1,000 h.p.-hrs.	$2,838.82
Cost of lubricating oil per kw.-hr.	0.0011
Cost of lubricating oil per h.p.-hr.	0.0007
Cost of repair parts	$1,659.50
Cost of repair parts per kw.-hr.	0.0007
Cost of repair parts per h.p.-hr.	0.0004
Cost of belts	$1,792.92
Cost of belts per kw.-hr.	0.0007
Cost of belts per h.p.-hr.	0.0005
Cost of miscellaneous supplies	$1,044.64
Cost of miscellaneous supplies per kw.-hr.	0.0004
Cost of miscellaneous supplies, per h.p.-hr.	0.0003
Total cost	$64,052.57
Total cost per kw.-hr.	0.0259
Total cost per h.p.-hr.	0.0160

and W. H. Adams, at the Panama-Pacific Exposition meeting of the American Society of Mechanical Engineers.

The equipment described includes four hot-surface, high-economy engines, two of 180 brake h.p., one 250 h.p. and the other at 280 h.p., belted or directly connected to the electric generators, operating at an altitude of 7,000 ft. and 90 miles from a railroad station, continuously for 24 hrs. per day.

The cost of hauling 90 miles is about 1 ct. per lb. The equivalent cost with fuel oil at 2 1/7 cts. per gal. and lubricant at 35 cts. per 1000 h.p.-hr. would be $45.70 per h.p. year at the engines and $74.50 per kw. year at the switchboard, instead of $136.51 per h.p. year with fuel oil at 16.5 cts. per gal. and lubricant at 71 cts. per 1000 h.p. hr. The figures do not include fixed charges of interest, taxes and insurance, and depreciation.

TABLE XXVII. RELATION OF ITEMS OF EXPENSE TO TOTAL OPERATING COSTS

Item	Under actual conditions (oil at 16.5 cts. per gal. and lubricant at 71 cts. per 1000 brake-h.p.-hr.) Per cent	With oil at 2 1-7 cts. per gal. and lubricant at 35 cts. per 1000 brake-h.p.-hr. Per cent.
Operating labor	12	36
Maintenance labor	3	10
Fuel	73	27
Lubricant	4	6
Repair parts	3	8
Belt renewals	3	8
Miscellaneous supplies..	2	5

In this comparison interest was assumed at 6%, depreciation at 6%, and insurance and taxes at 2%, the first cost being only approximately correct.

TABLE XXVIII. ECONOMY TEST OF 300 H.P. ATLAS ENGINE (After C. E. Sargent, consulting engineer).

R. p. m......	174.7	174.1	173.1	173.1	172.9	171.9	171.0
Brake h.p. developed	74.0	100.4	171.4	229.2	261.7	269.4	331.7
Fuel, lbs. per hr.	50.0	61.3	81.0	108.0	120.4	128.0	167.0
Fuel, lbs. per b. h.p.-hr.	0.67	0.61	0.472	0.47	0.46	0.476	0.503
Fuel, lbs. per kw.-hr. ..	1.04	0.93	0.71	0.7	0.68	0.7	0.74
B.t.u. per b. h.p. per minute* .	214	194	151	150	147	152	160
Therm. eff. of engine†	19.8%	21.7%	28.1%	28.3%	28.9%	28.0%	26.4%
Cost of fuel per kw.-hr. at 2 cts. per gal., cts..	0.284	0.254	0.194	0.192	0.185	0.191	0.203

* Calorific value of fuel, 19,150 b.t.u. per lb.

† Therm. eff. = 2545 ÷ b.t.u. per b. h.p.-hr.

CHAPTER IX

HYDRO-ELECTRIC PLANTS

Unit Basis for First Cost Estimates of Hydro-Electric Plants. Farley Gannett (Engineering Record, Aug. 9, 1911) states that in the case of storage propositions, where a continuous power output is available, and when each unit could, if the demand were uniform, be worked to its best capacity, uniformly throughout the year, the cost per horse-power installed naturally works out larger than in the case of most uncontrolled river powers, where provision is made for utilizing the average flow of the 7 or 8 months of large discharge, involving the disuse for 4 or 5 months of a considerable part of the machinery. Recent examinations of certain large storage propositions have brought this point forcibly to notice, through the large unit first cost as computed on the usual basis. But even in this class of propositions such a basis is misleading on account of the load factor to be considered.

For example, take a proposed 8,000-h.p. proposition recently reported on, with storage sufficient to maintain this output throughout 24 hours every day of the year. If this plant were to be used to supply power day and night with a load factor approaching 100%, the installation would be say 10,000 h.p., and at an assumed cost of $1,500,000 the cost per h.p. installed would be $150, which, according to usual standards, would not indicate an exceptionally good proposition if it involved the use of a variable river. If, however, this plant were to operate the trolley system of a large city, with a load factor of less than 50%, the installation would be, say 20,000 h.p. and the corresponding unit cost per horse-power would become about $85, allowing for cost of additional machinery, larger penstocks, etc., which, according to accepted standards, would be quite feasible. As a matter of fact, the proposition is no better, its output of power no more, and its cost would necessarily be somewhat greater on account of the additional machinery, while the interest, maintenance and depreciation charges would be increased. The selling price of the power would be greater, however, under the latter conditions, but presumably not in proportion to the reduced unit first cost per h.p. installed.

What is required of the first-cost unit price is that it shall indicate directly the actual cost of something which yields a definite annual income; something which the whim of the designer cannot greatly alter, something which, in the case of uncontrolled streams, involves the variations of flow and shows conditions at their worst from the income standpoint; something which will show up a con-

stant-power storage proposition in its true worth as against a variable-power, and above all else will require as a prerequisite a fairly definite knowledge of the seasonal variations of flow of the stream to be used. The first cost per installed horse-power has been in some instances misused in connection with large river powers and by reason of large machinery installations this figure has been so reduced as to bring discredit on water power propositions of great value. In order to protect good water powers and to prevent poor ones from enticing the money of investors, a more trustworthy unit of first cost would seem advisable, and it is suggested that the first cost per kilowatt-hour, as determined from the division of the entire cost by the total number of kilowatt-hours that can be produced in the dryest years, based on actual daily discharge records where available, is to be preferred over the present unit. Thus in the case of a variable river power, this unit cost would represent conditions at their worst and therefore the safest for the intending investor. It would take into account the installation for utilizing secondary power and would also involve the minimum output of constant power.

For example, consider a proposition examined a few years ago on an uncontrolled river, where a head of 28 ft. is available and 4,000 h.p. of turbines was installed at a total cost of something like $700,000. On the present basis this would represent a cost of $175 per h.p. During the dry season the flow in this river is depleted to about 100 sec.-ft. and the available flow for 6 months in the dryest year averages about 200 sec.-ft., giving an available power of about 500 h.p. Assuming the full 4,000 h.p. for 6 months and 500 h.p. for the other 6 months, the total yield of power if, as in this case, the pondage can take care of the load factor variations in a dry season, would be practically 14,500,000 kw.-hrs. Dividing this figure into the $700,000 first cost gives 4.8 cts. per kw.-hr. In other words, it costs 4.8 cts. to install the necessary machinery to produce the average kw.-hr.

Consider on the other hand the 8,000-h.p. storage proposition above referred to, at a cost of $1,500,000. In this case the power is uniform throughout the year, and the installed machinery is regulated by the probable load factor. The output of this plant is 52,500,000 kw.-hr. and the cost per kw.-hr. output in the minimum year is therefore 2.9 cts.

The above computations indicate that on the horse-power installation basis the variable river power costs $175 per h.p. and the storage proposition costs $150 per h.p. for a 10,000 h.p. installation, or about 90% as much, while on the unit basis herein suggested the former costs 4.8 cts. per kw.-hr. of output and the latter only 2.9 cts. or 60% as much, and evidently represents far more accurately the relative merit of the two propositions.

Another advantage of this method of determining the unit first cost is the facility which it affords in determining the relation between revenue and cost. The cost per kw.-hr. divided into the kw.-hr. price at which power will be or is sold, gives immediately the percentage of gross return on the investment. For example,

in the case of the plant costing 4.8 cts. per kw.-hr. output, at 1 ct. per kw.-hr. selling price, the gross return on the investment would be, in the worst year, with all the power contracted for, 1/4.8, or approximately 20%, and similarly for whatever average price it is anticipated the power can bring.

Cost of Hydro-Electric Power Plants. W. H. Weston in Engineering Magazine, Jan., 1912, says that costs range from $50 to $500 per h.p., many of the larger plants costing more than $150 per h.p. The first cost naturally is much more than for steam plants, generally on account of the following items: The water wheels and connections, a small item; water privileges, which are very expensive, either directly or indirectly; one or more dams with head- and tail-races, which may in themselves often amount from $25 to $50 per h.p. and more. Foundations for hydro-electric plants generally cost more than for steam plants; there are also, consequential damages from the flooding of the land above the dam.

From Mr. Weston's experience, depreciation in water-power plants will range from 1½ to 2¼% per year, with 2% for a general average and repairs about 1% per year. Considering the hydro-electric power on an economical basis, he calls attention to the following very interesting points where such a plant is to compete against a steam design:

1. How is the raw material located with reference to the power; what is the distance to a market, and what are the transportation facilities?
2. How much power can be obtained?
3. Will this amount of power be continuous, regular, and reliable?
4. What will be the total cost of developing the water power and building the business plant which it is to operate? And what will interest, insurance, taxes, deterioration and repairs amount to?
5. Is steam necessary for use in the process of manufacture, and to what extent?
6. Is water power capable of giving sufficient regularity in operation of the machinery?
7. What will be the cost of transportation of products and of supplies?
8. What would be the total cost of operating the water power plant at a given place, compared to that of a steam plant erected at a location that would be advantageous?
9. What are the opportunities for obtaining good employees?

Mr. Weston also gives — interest 5%, taxes and insurance 1%, depreciation 2%, repairs 1%, making a total of 9% for a water power, as against 13% as a fair figure for the same items in a steam plant.

Cost of Hydro-Electric Power per Horsepower. In a series of articles in the Journal of the Franklin Institute, October, November, December, 1901, C. D. Gray gives an extended discussion of the cost of power under various conditions, and from these papers the following abstract is made:

The costs of hydro-electric power plants are widely different,

depending upon the location, size, and extent of the hydraulic works needed, length of penstock and flume, and many other things that differ in the various localities. Below are given some figures in regard to the costs of plants. These are low-head plants fitted with turbine wheels, and are used principally for mill or factory purposes. The costs do not include costs of dam unless so specified, but include everything else in the plant. The horse-power basis

TABLE I. HYDRO-ELECTRIC PLANT COSTS PER HORSE-POWER

Place	Cost per h.p. delivered	Authority
Lawrence, Massachusetts	$ 68.67	Manning, A.S.M.C., Vol. X, p. 499.
Manchester, New Hampshire	66.00	
Lowell, Massachusetts, 13 ft. head	110.00	C. T. Main, A.S.M.E., Vol. XI, p. 108.
Lowell, Massachusetts, 18 ft. head	57.00	
Lawrence, Massachusetts	63.00	
Lawrence, Massachusetts, 1,000 h.p.	67.50	
Concord, N. H. (with dam)	57.75	Webber, A.S.M.E., Vol. XVII, p. 41.
Augusta, Georgia	34.20	
Columbia, South Carolina	37.50	
Caratonk Falls, Maine (with dam)	24.00	
Omaha, Nebraska (estimate)	67.33	Eng. Mag. Vol. VII, p. 409.
Zurick (with dam)	100.00	Eng. Mag., February, 1900.
Paderna, Italy (with dam)	120.00	
Big Cottonwood, 3,000 h.p.	108.25	Eng. News, October 1, 1896.
Average without dam (excluding Lowell) $100	$53.41	
Average with dam	79.55	

TABLE II. COST OF HYDRO-ELECTRIC POWER PER HORSE-POWER-YEAR

Place	Cost per h.p.-year	Authority
Lawrence, Massachusetts	$13.70	C. T. Main, A.S.M.E., Vol. XIII, p. 140.
Canada (lowest)	6.25	Meyer, Sci. Am., February 9, 1882.
Cottonwood	16.10	Eng. News, October 1, 1896.
Lawrence, Massachusetts, 1,000 h.p.	22.62	Manning, A.S.M.E., Vol. X, p. 48.
Lawrence, Massachusetts, 500 h.p.	19.13	Main, A.S.M.E., Vol. XIII, p. 140.
Concord, New Hampshire	8.64	Weber, A.S.M.E., Vol. XVII, p. 41.
Augusta, Georgia	11.05	
Columbia, South Carolina	9.50	
Omaha, Nebraska (estimate)	8.08	Eng. Mag. Vol. VII, p. 409.
Norway (electrolytic work)	11.25	Chem. Ind., Vol. XXIII, p. 121.
Niagara (sold for)	13.00	Emery, A.I.E.E., Vol. XII, p. 358.
Estimate on plant	5.42	Webber, W. O., Eng. Mag., Vol. XV, p. 926.
Average of the above	$10.72	

upon which they are figured is the horse-power delivered at the wheel shaft.

It is probable that the cost of such plants will be from $40 to $60, excluding the cost of dam, but including all other parts; and when the dam is included that it will be from $60 to $100. Webber, in Iron Age, February and March, 1893, says that water-power plants can be put in for $100 per h.p.; and Stilwell, in American Institute of Electrical Engineers, Vol. X p. 484, says that the cost may be as low as $65.

The cost of hydro-electric power per h.p.-yr. is variable, depending, as it does, upon the first cost of plant; and hence no very good average can be found. Table II may serve to show the costs in some cases that have been reported.

From Table II it may be seen that the cost per h.p.-yr. is $10.72. Webber gives it as $10 to $12 (Iron Age, February and March, 1893); and Conant, in an article in the Street Railway Journal for October, 1898, gives the cost as ranging from $10 to $22.40. A fair average may be taken as varying from $10 to $15.

Cost of a Subterranean Hydro-Electric Generating Plant in Sweden. The following table given in Electrical World, May 10, 1913, covers the generating and transmission equipment of the Vesterdalafven Power Company at Mockfjärd and comprises part of a 65,000-h.p. interconnected system.

Cost of the entire development was as follows:

Water rights and real estate		$223,640
Dwellings and engineering		17,240
Dam, flume and tunnels		478,980
Generating room and switch house		102,320
Machinery:		
Turbines and governors	$ 31,720	
Generators	64,250	
Transformers	28,290	
Switch gear	42,360	
		166,820
Distribution system:		
Grängesberg-Mockfjärd	$112,860	
Nyhammar substation	21,270	
Secondary lines	5,310	
Overhead charges, interest, etc.	113,530	
		252,970
		$1,241,970
Cost per horse-power		$62.10

A general idea of the plant development is given by Fig. 1.

General Conditions. The wheel chambers are cylindrical, 21.3 ft. in diameter, lined to a steel and back filled with concrete and contain four double-runner Francis turbines, of 5,100 h.p. at 225 r.p.m., rated each, horizontally mounted at the bottom of these chambers, with shaft centers 24 ft. above the lowest tail-race level.

Two wheels discharge into the same tunnel, about 5,000 ft. long with a 322.8 sq. ft. cross-sectional area. In the roof, at a distance of 164 ft. from the turbines, are large pockets of about 2,000 cu. yds. in volume each. These pockets are interconnected and pro-

vided with vertical shafts, to prevent water hammer. The general plant is indicated in Fig. 2.

The dam is built on bedrock with steel and concrete piers faced with steel plates on the upstream sides. The spillway crest has an elevation of 76.45 ft. There are 64 wooden gates running in re-

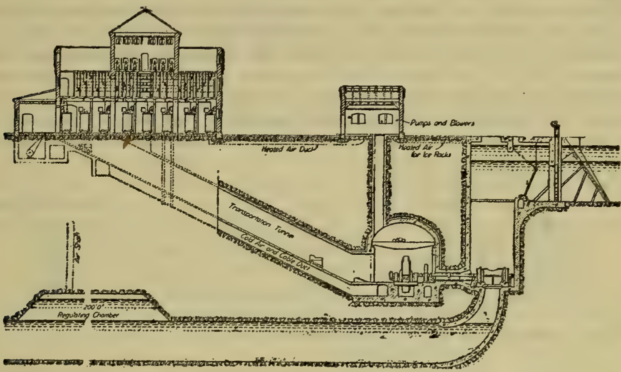


Fig. 1. Section of dam, generating room and switch house.

moval steel guides, providing large openings for removal of debris, four steel headgates, and one large steel sluicegate, which is 19.7 ft. wide and 26.3 ft. deep and is divided horizontally into two parts, thus providing for discharge during floods and for draining the pool for repairs of the dam and the screens. This construction avoids a large superstructure and makes available the use of the

Fig. 2. Location of Mockfjard development.

lower part of the gate for regulating the water level, this lower part being always free from ice. All gates are operated electrically and also by hand. There is a 6,500-ft. long steel flume for logging, a capacity of 40,000 ft. b.m. of timber per day, and also a salmon way and eel ladders.

Generating equipment comprises four 4,500-kv.a., 6,600-v., three-phase units operating at 225 r.p.m. and 60 cycles.

The cars are transformed 50,000-volt for the two outgoing lines to Grängesberg and Domnarfvet, 30 miles and 20 miles respectively. On the longer line the conductors are carried on A-frame and square-base towers average distance of 655 ft. On the shorter line the towers are wooden poles 46 ft. long and 9 ins. in diameter, on concrete foundations, with average span of about 540 ft.

Relation of K.W. Cost to Size of Plant in Switzerland and Sweden. H. A. McBride, in a consular report (1912), gives some interesting general data relative to Swiss hydro-electric plants. About 160 hydro-electric plants having a combined capacity of 342,000 k.w. have reported their construction costs, showing the following results:

Size of plant	Cost per k.w.
100-k.w. or less	$467
100 to 500-k.w.	281
5,000 to 6,000-k.w.	177
20,000 to 30,000-k.w.	161
Average of all	211

This average of $211 is divided thus:

	Cost per k.w.
Hydraulic plant	$116
Electric plant	95
Total plant	$211

The $95 of electric plant includes the transmission lines and probably it includes the distribution lines also.

In the Swedish hydro-electric plant at Mockfjärd water from the river is diverted by a dam and through a discharge tunnel, 5,000 ft. long, giving a head of 78 ft. The water wheels and generators are located in subterranean chambers. There are four horizontal turbines of 5,100 h.p. each, at 225 r.p.m., direct connected to four generators, each of 4,500 kv.a. (or 3,800 kw. at 85% power factor). It is not clear why the water wheels were not given about 25% greater capacity than the rated capacity of the generators instead of being practically the same capacity; for generators are commonly designed to carry 25% overload for a short time. Assuming the rated capacity of the generators to be 15,000 kw., the following was the cost of the plant:

	Cost per k.w.
Water rights and real estate	$14.91
Dam, flume and tunnels	31.93
Generating room and switch house	6.82
Turbines and governors	2.11
Generators	4.28
Transformers	1.89
Switching apparatus	2.82
Total	$64.76

Transmission lines	$ 7.87
Substation	1.42
Dwellings and engineering	1.15
Overhead charges, interest, etc.	7.57
Total cost per k.w.	$82.77

This entire plant is very inexpensive, but the low cost of the turbines is particularly noteworthy. In America the cost of the waterwheels is commonly about the same as the cost of the generators.

Cost of Power in Switzerland. The following costs were abstracted from the Proceedings of the National Electric Light Association, May, 1911:

Owing to the development of hydro-electric energy the importation of coal into coalless Switzerland has actually failed to increase over a period of ten years. Among 266 stations there are 173 which had their own power plants and 93 which bought energy in bulk from other stations. A large majority of the 173 stations used water power either alone, or together with steam power. The mean first cost invested per kw. is $207 for the water power stations, $265 for combined water power and steam stations and $627 for stations using gas power alone. Out of the 173 stations 57 produced direct-current, 85 alternating-current and 31 both direct-current and alternating-current. The total length of the most extended transmission was 410 miles, that of the most extended distributing system 490 miles, both employing overhead wires. The maximum distance over which electrical energy was transmitted was from 60 to 120 miles. The aggregate rating of 752 hydraulic turbines and steam engines, and electric-motor generators supplied with energy in bulk from other stations was 289,865 h.p., giving a mean of 385 h.p. per generator.

The possible output of the water power stations of Switzerland had a maximum of 213,000 h.p. and a minimum of 132,870 h.p. at times when the water is low. The rating of the motors and lamps connected to the 173 stations was 206,800 kw. Of these there were 87,300 kws. in motors, 102,800 kws. in incandescent lamps and 17,000 kws. in heating apparatus, etc. At the present time figures would be probably about 20% higher than in 1908. The development of water power in Switzerland began in 1886, and by 1890 there were 12 plants with a rating of 40,000 h.p. Of the 152 hydro-electric plants existing in 1907, 65 had steam reserves with an aggregate rating of 50,000 h.p. Other low-pressure water power plants used a water storage system. An excellent method of utilizing all the water is to combine a low-pressure plant with a high-pressure plant with a switch lake. Data given on some of the more important plants, also of the financial returns of fifteen stock companies having a stock capital of more than $200,000 each, show that interest on the capital is paid only after from two to six years. In 1909 the dividend for these fifteen companies varied between 3% and 8%, the average being 5.3%.

The rates in Switzerland for industrial power are thus quoted,

Cost of Developing a Water Power at Vallorbe, Switzerland. The height of the fall is 229 ft., and 3,000 h.p. is developed.

The expenditures were divided as follows (see Compressed Air, Jan., 1908).

Concession and land	$ 6,000
Dam	4,000
Tunnel, etc.	10,000
Pipe line	6,000
Turbines and sluice-gates	22,000
Buildings	4,000
Dynamos	60,000
Sundries	8,000
	$120,000

Thus the cost per h.p. was $40. Interest and depreciation at 10% make $4 per h.p. per annum. These results are exceptionally favorable, even for Switzerland; more usually the cost of installation would average $80 per h.p., and the annual charges $8.

Cost of Various Hydro-Electric Developments in Ontario. The costs given in Table III are from the 1910 report of the Ontario (Canada) Hydro-Electric Power Commission and are based on engineer's estimates.

TABLE III. COST PER HORSEPOWER OF HYDRO-ELECTRIC POWER DEVELOPMENT IN ONTARIO

Location of development	Natural head	Available head	Power developed h.p.	Estimated capital cost	Cost per h.p.
Healey's Falls, Lower Trent River	..	60	8 000	$675,000	$84.38
Middle Falls, Lower Trent River	..	30	5,200	475,000	91.37
Rauney's Fall	..	35	6,000	425,000	69.67
Rapids above Glen Miller	..	18	3,200	350,000	109.38
Rapids above Trenton	..	18	3,200	370,000	115.63
Maitland River[1]	..	80	1,600	325,000	203.12
Sangeen River	..	40	1,333	250,000	187.53
Beaver River (Eugenia Falls)	..	420	2,267	291,000	128.28
Severn River (Big Chute)[2]	..	52	4,000	350,000	87.50
South River	..	85	750	150 000	153.33
St. Lawrence River, Iroquois, Ont.	..	12	1,200	179,000	149.16
Mississippi River, High Falls, "A"[3]	..	78	2,400	195,000	81.25
Mississippi River, High Falls, "B"	..	78	1,100	123,000	181.82
Montreal River, Fountain Falls, Ont.	..	27	2,400	214,000	89.16
Dog Lake, Kaministiquia River[4]	347	310	13 676	832,000	61.00
	347	310	6 840	619 700	91.00
Cameron Rapids	39	...	16,350	815 000	50.00
	39	...	8,250	600 000	73.00
Slate Falls	31	40	3,686	357 600	97.00
	31	40	1,843	260,000	141.00

[1] Dam rather expensive. [2] Head works and canal less expensive than ordinary. [3] With storage development. [4] Including 3,500 ft. of headwater tunnel.

TABLE IV. ESTIMATED COSTS OF HYDRO-ELECTRIC POWER AND TRANSMISSION IN THE PROVINCE OF ONTARIO, CANADA

Source of power	Population	Present power used, total	Portion admitting electrical installation	Future load estimated h.p	Distance of transmission, miles	Annual charges per h.p. Generation	Transmission	Step-down transformation	Administration	Inter-switching	Total cost 24-hr. power.
Healy's Falls, 8,000 h.p. at a cost of $84.38 per h.p.	19,400	2,600	2,200	2,750	98	$13.50	$5.42	$2.12	$0.36	$0.03	$21.43
	10,200	2,065	3,600	4,500	50	12.87	1.71	1.69	0.36	0.03	16.66
	4,920	1,640	1,460	1,825	85	13.35	5.51	2.27	0.36	0.03	21.52
	2,250	380	250	312	90	13.52	8.82	4.60	0.36	0.03	27.33
Maitland River, 1,600 h.p. at a cost of $203.12 per h.p.	4,300	1,450	500	625	4	14.12	1.57	...	0.75	...	16.44
	2,800	2,800	200	250	9	16.83	4.59	4.30	0.75	...	26.47
	2,200	2,200	200	250	29	16.83	4.59	4.30	0.75	...	26.47
Beaver and Severn Rivers, 2,267 and 4,000 h.p. at a cost of $128.28 and $87.50 per h.p.	10,000	3,750	2,000	2,500	89	12.90	4.14	2.12	0.91	0.15	20.22
	7,000	1,650	1,000	1,250	53	12.95	5.30	2.65	0.91	0.15	21.96
	400	600	*	400	17	12.70	1.09	3.78	0.91	0.15	18.63
Iroquois, 1,200 h.p. at a cost of $149.16 per h.p.	9,000	700	700	875	27	22.50	5.07	1.64	3.34	...	32.55
	3,035	215	215	208	15	21.97	2.57	4.69	3.19	...	32.42
High Falls, Mississippi River, Scheme A, 2,400 h.p. at a cost of $81.25 per h.p.	9,000	700	700	875	63	12.13	7.27	2.30	3.98	...	25.68
	3,035	215	215	208	75	12.13	16.10	4.38	3.97	...	36.58
	5,700	815	300	504	35	11.54	2.95	3.88	3.83	...	22.20
	4,000	240	150	210	23	11.27	1.76	5.75	3.73	...	22.51
High Falls, Mississippi River, Scheme B, 1,100 h.p. at a cost of $111.82 per h.p.	5,700	815	300	504	35	16.00	6.42	3.00	4.93	...	30.45
	4,000	240	150	210	23	15.55	3.72	5.00	4.79	...	29.16
Fountain Falls, Montreal River, 2,400 h.p. at a cost of $89.16 per h.p.	*	1,800	1,400	2,800	15	18.30	1.64	1.73	2.50	...	24.17
	*	1,000	800	1,600	12	18.22	1.24	2.35	2.48	...	24.29
	1,215	200	200	400	20	18.52	5.37	5.21	2.54	...	31.64
Dog Lake, 13,675 h.p. at a cost of $61.00 per h.p.	10,200	....	....	13,382	25	6.41	0.92	1.21	0.56	...	9.10
Cameron Rapids, 16,350 h.p. at a cost of $50.00 per h.p.	10,200	....	....	13,382	75	5.91	2.16	1.19	0.49	...	9.75
Slate Falls, 3,686 h.p. at a cost of $97.00 per h.p.	860	....	....	3,300	26	9.66	1.67	2.96	0.43	...	14.72
	1,350	....	....	150	16	9.67	1.03	15.96	0.44	...	27.10

* Indefinite.

Cost of Hydro-Electric Power Development for a Large Area in Ontario. As a basis for estimates in demand for power made by a power commission of the Province of Ontario, Canada, in 1910, a full canvass was made by expert assistants in each town and city. Great care was taken to determine whether or not the consumer would be likely to adopt electric power if it were available, and a distinction was made in the case of power users who required steam for other puurposes or who had refuse material available as fuel and who consequently would not be apt to make a change in their source of power.

In estimating the total power to be distributed in each municipality it has been arbitrarily assumed that by the time transmission lines could be completed and with power for sale at reasonable figures the total demand which should be provided for would be 25% greater than present estimates. On this basis weight of copper was calculated.

Having determined the cost of 24-hr. power to various municipalities, its distribution was to be considered separately for customers in each town or city. Owing to the great amount of labor involved in working out the costs of a system for each small place it was considered sufficient to take typical cases and apply the results more widely. Little variation was found in the cost of distribution in places of moderate size where underground distribution was not necessary.

In the estimates on which the cost data table has been compiled, depreciation and replacement charges have been figured so as to replace the different classes of equipment in periods ranging from 15 to 40 years. The depreciation charges are held as sufficient to serve as a sinking fund. However, in the case of the generating station estimates, the depreciation figures do not include enough to replace the so-called permanent portions of the development such as dams, head works and power-house. If a 40-year sinking fund large enough to cover these items is considered necessary a charge on some $45 to $65 per h.p. of capacity would need to be made. At 3 or 4% a charge of 60 to 80 cts. per annum per h.p. would meet the requirements. The given annual charges include

TABLE V. CAPITAL COSTS AND ANNUAL CHARGES ON MOTOR INSTALLATIONS, POLYPHASE, 60-CYCLE INDUCTION MOTORS.

Capacity. H.p.	Capital cost per h.p. installed	Annual charges: Interest 5%	Depreciation and repairs 6%	Oil, care and operation	Total per hp. per annum
5	$39.00	$1.95	$2.34	$4.00	$8.29
10	36.00	1.80	2.16	3.00	6.96
15	30.00	1.50	1.80	2.50	5.80
25	25.00	1.25	1.50	2.00	4.75
35	22.00	1.10	1.32	1.75	4.17
50	20.00	1.00	1.20	1.50	3.70
75	19.00	.95	1.14	1.25	3.34
100	17.00	.85	1.02	1.00	2.87
150	15.00	.75	.90	.80	2.45
200	14.00	.70	.84	.70	2.24

depreciation, repairs and interest during construction. The transformation charges include municipal taxes on building, insurance, depreciation and 20% for engineering contingencies and interest during construction.

By combining the above costs with those given in Table V the total charge per h.p.-yr. is obtained.

Cost of Hydro-Electric Plants at Niagara Falls. Table VI is from the 1910 report of the Ontario Hydro-electric Commission and is based on engineers' estimates.

TABLE VI. COST OF HYDRO-ELECTRIC PLANTS AT NIAGARA FALLS

	24-hour power capacity 50,000 h.p. development	75,000 h.p. development	100,000 h.p. development
Tunnel tail races	$1,250,000	$1,250,000	$1,250,000
Headworks and canal	450,000	450,000	450,000
Wheel pit	500,000	700,000	700,000
Power house	300,000	450,000	600,000
Hydraulic equipment	1,080,000	144,000	1,980,000
Electrical equipment	760,000	910,000	1,400,000
Transformer station and equipment	350,000	525,000	700,000
Office building and machine shop	100,000	100,000	100,000
Miscellaneous	75,000	75,000	75,000
	$4,865,000	$5,900,000	$7,255,000
Engineering and contingencies	485,000	590,000	725,000
	$5,350,000	$6,490,000	$7,980,000
Interest, 2 years at 4%	436,560	529,584	651,168
Total capital cost	$5,786,560	$7,019,584	$8,631,168
Per horse power	$114	$94	$86

Yearly Cost of Power, Chicago Sanitary District System. (After Frank Koester in Engineering Magazine.) The following table gives the distribution of yearly cost in 1910.

Capacity of plant, horsepower	15,500
Total cost of development and transmission	$3,500,000
FIXED CHARGES	
Interest on investment at 4%	$140,000.00
Taxes on real estate, buildings, etc.	7,200.00
Depreciation of buildings at 1%	3,650.00
Depreciation on water wheels at 2%	2,027.32
Depreciation on generators at 2%	1,824.60
Depreciation on pole lines at 3%	2,020.50
Depreciation on other electrical appliances at 3%	3,995.52
Total fixed charge	$161,137.94
OPERATING EXPENSES	
Power and substation labor	$ 63,240.00
Repairs to machinery and buildings	3,700.00
Incidental expenses	1,200.00
Operating Lawrence Avenue pumping station	43,960.00

Operating 39th Avenue pumping station	120,380.00
Interest on investment 39th St. pumping station	15,599.76
Total operating expense	$248,079.76
Total cost to sanitary district	$409,217.70
Cost per h.p. per annum	$26.40

Cost of a 1,400 Kilowatt Hydro-Electric Plant. The data from which the following summary of costs of a small plant at Eugene, Ore., were prepared appeared in Electrical World, May 17, 1913, and Dec. 10, 1912.

	Total	Per k.w.
1. Intake	$ 3,971	$ 2.84
2. Canal	90,171	64.40
3. Headgates	4,514	3.22
4. Flume, forebay and wasteway	10,604	7.57
5. Water wheels and pressure pipe lines	25,656	18.35
6. Electric apparatus	22,097	15.78
7. Station buildings and grounds	9,299	6.64
Total of items 1 to 7	$166,312	$118.80
8. Transmission line	12,164	8.69
9. Substation apparatus	5,631	4.02
10. Substation building and grounds	813	.58
11. Real estate and right of way	12,164	8.69
12. Miscellaneous	112	.08
Total of items 1 to 12	$197,196	$140.86
13. Distribution lines and transformers	22,419	16.01
14. Meters	9,724	6.94
15. Series street lighting	17,676	12.63
16. Ornamental posts	7,324	5.23
Total of items 1 to 16	$254,339	$181.67
17. Supervision	4,755	3.40
18. General office	4,417	3.16
19. Interest during construction, and bond expense	20,755	14.82
Grand total	$284,266	$203.05

Note: Item 2 includes excessive charges of $26,257, due to failure of contractor and court costs.

Water from the McKenzie River is diverted through a canal 19,400 ft. long and wooden flume 650 ft. long, designed to carry 500 second-ft. The canal headgates are of concrete, located in the canal 350 ft. below the intake.

There are two wood stave pressure pipes, 8 ft. diam., each 100 ft. long, bedded on timber cradles 12 ft. apart. Just before entering the power station the stave pipe connects to a 96-in. riveted steel Y which carries the water to the turbine of each unit.

There are two turbines, each 1,200 h.p., Pelton Francis type, direct connected to Fort Wayne generators. Each generator is rated at 705 kw. or 945 h.p. This difference between turbine and generator rating indicates that the generators are designed to carry a 25% overload for a short time (probably two hours) without excessive heating. The generators are 2,300-volt, 60-cycle, 3-phase, 300 r.p.m.

The hydraulic head on the shaft centers of the wheels is 28 ft. and the draft head is 15 ft., giving a total head of 43 ft.

The power plant building has a concrete foundation and floor, and corrugated iron walls on a wooden frame.

The current is stepped up to 23,000 volts, by means of one bank of three kws. Westinghouse oil-insulated, water-cooled units, delta connected, which have a 50% overload capacity for an hour without undue heating. A fourth spare unit is provided.

The transmission line to Eugene is 15.5 miles long, and its cost was not quite $800 per mile, including a telephone line. Cedar poles are spaced 40 to the mile. Three wires of No. 4 copper are mounted on Pittsburgh single-petticoat porcelain insulators, 8 ins., 40,000 volts. There is one river crossing of 670 ft. span.

The substation transformers are installed in a part of the city water-filtration plant building, which accounts for the low cost of "substation buildings." The current is stepped down to 2,300 volts, and carried in three-phase circuits. Line transformers deliver the current at 230 and 115 volts.

Thirty miles of streets are lighted with incandescents. On Dec. 1, 1911, only two customers were being served; but 1,001 customers were served Dec. 1, 1912.

Cost of a 36,000 K.W. Low Head Plant in Massachusetts. In the plant of the Turners Falls Power and Electric Co., at Montague City, Mass., described in Electrical World, Apr. 21, 1917, owing to the low head, normally 55 ft., and the size of the units, low-speed machinery was adopted. The wheels are a little out of the ordinary, being of a single-runner type with vertical shafts bearing the usual

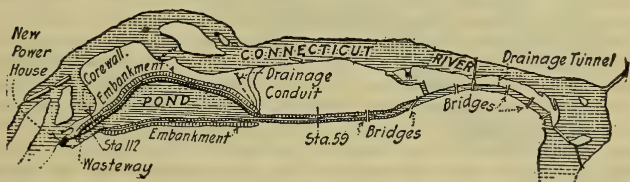


Fig. 3. Canal and pond for Turners Falls hydro-electric plant.

umbrella type generator adopted for such construction. The generating units, despite their low speed, were of moderate cost, figuring only $6.31 per kw. on full rating, while the total development cost only $65 per h.p., an unusually low figure for this part of the country. The hydroelectric development was decided on after a thorough examination of the possibilities of the situation, ending in the present scheme of enlarging and extending an earlier canal from the old site, utilizing the water at one point as far as possible and thereby avoiding a second dam across the river.

Canal, Fig. 3, is about 2¼ miles long from the mouth of the canal to the power plant. Through the town of Turners Falls it runs through rock, but beyond this town the canal broadens out

into a rock-lined earth cut. At the lower end the canal widens still further into a forebay pond about 600 ft. wide on the average and 3,000 ft. long. For the last one-fifth of a mile to the generating station the canal narrows down to 150 ft. wide by 25 ft. deep. A 5-ft. drainage conduit extends from the head of the pond to the river. Because of the size of the pond sudden increases in load can be handled without drawing down the head to a troublesome degree before the headgates can be opened.

On the river side of the canal just above the power house is a wasteway, with a concrete spillway and ten 12-ft. by 10-ft. wooden gates mounted between piers. The gates are operated by hoists mounted on a concrete platform extending across the piers, the hoists being gear-driven through a common shaft by a 50-h.p. motor controlled from the generating station switchboard. The wasteway has sufficient capacity to handle the full canal flow. In addition it can be used for the removal of ice from the canal, in unwatering the latter, and in case of a sudden dropping of the load can be used as a spillway. The discharge of the wasteway follows a gentle slope to the river, a part of the incline containing a rocky bed which breaks up the rush of water.

The Power House is 235 ft. long and 85 ft. wide, the long axis being parallel to the river and making an angle of 20 degs. with the center line of the canal. The head wall of the station contains racks and headgates, the latter being raised by an electric gantry crane running on the head wall. The crane is equipped with a mechanical trash collector by which the racks can be cleared, the trash then being dumped into a special sluice behind the racks and discharged into the river by flushing parallel to the canal and thence into a canal drain at the lower end of the power house.

Behind the racks are concrete piers separating the intake into three penstock chambers per generating unit. The headgates are made of steel and operate on a chain of rulers which enables them to close by force of gravity. Strictly speaking, there are no penstocks in the plant, there being instead merely passages in the concrete foundation of the building leading to the various wheels. These passages curve downward from the headgates to the scroll cases of the wheels, the latter being set 18 ft. above low water. At the scroll cases the 3 passages from each group of 3 gates merge into one. Water enters each wheel through 20 openings around the circumference, each opening having a wicket gate controlled by the governing mechanism. The head on the wheels is normally 55 ft. The penstocks, scroll cases and draft tubes are faced with smooth concrete 12 ins. thick of a slightly different mixture from that used for the station foundations. Foundations are new completed for all six units.

The Wheels are of the vertical, single-runner type, rated at 9,700 h.p. each, built by the I. P. Morris Company of Philadelphia, which also furnished the governors. Kingsbury thrust bearings are provided for these units. Each wheel drives a 7,500-kv.a. 6,600-volt, three-phase, revolving-field alternating at a normal speed of 97.3 r.p.m., the system frequency being 60 cycles. On top of

the main shaft of each unit is mounted a 95-kw. exciter, designed for 250-volt service to save copper. The governors are connected with the shafts by flexible gear drive, which is said to eliminate the troubles sometimes arising from belting. A spare motor-driven exciter rated at 100 kws. is installed in a fireproof compartment off the operating room for emergency service. Each generating unit has a lignum-vitae guide bearing lubricated by water received from the scroll case through a Terry cloth filter. The

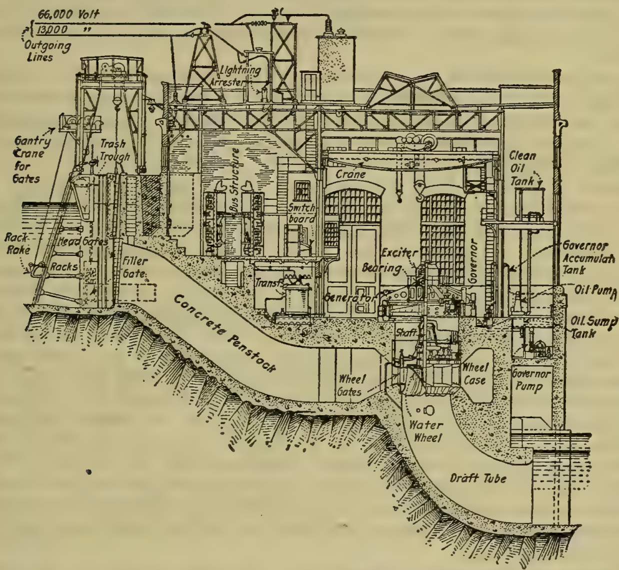


Fig. 4. Cross section of Turners Falls hydro-electric plant.

total area of the water passages leading from each set of gates to each unit is about 15 ft. by 27 ft. Single-runner vertical units were selected because they offer no obstruction to the flow of water out of the wheel and because they are reliable and simple. The tailwater is discharged into the river 22 ft. below the surface. The ultimate rated capacity of the plant (36,000 kw.) is based on a river flow of 10,000 second-feet.

A water-cooling coil is installed in each thrust bearing, consisting of 145 ft. of 1⅛-in. copper tubing per unit. Fifteen gallons of oil per min. is required to carry off the heat developed in each thrust bearing. The water for the auxiliary cooling service can be taken either from the canal or from the municipal supply. In the center of the station over the tail-race is a pump pit containing motor-

driven oil and water pumps for lubricating and governor-operating service. The governor pumps are horizontal centrifugal units rated at 325 gals. per min. each against a 525-ft. head, and are directly driven by 100-h.p. induction motors, which are automatically started and stopped from a.c. motor control panels. Two sump tanks are installed in the pump pit and are cross-connected by a suction main from which the pump suctions are taken. The pumps discharge into a pressure main, to which is connected a pair of accumulator tanks mounted on the operating-room floor, the governor-operating cylinders being fed from the pressure mains and discharging into a receiving main leading back to the sump tanks.

Each accumulator tank is divided into two sections by a diaphragm, the upper section being open to the air and connected with the discharge main by a relief pipe. Once a week compressed air is forced into the governor-operating system to provide an air system at the top of the lower section of each accumulator tank. The air is furnished by a compressor driven by a 5-h.p. motor, a 0.5-in. supply pipe being run to each accumulator tank. A hand-operated pump is installed on the operating-room floor to enable the gates to be closed if the water supply is interrupted. Five sets of wooden block brakes actuated by compressed air are provided on each generator as they may be forced against the rotor-rim flange when it is desired to bring a machine to a standstill promptly. Waterwheels were furnished with a rating of 9,700 h.p. in order to insure the driving of the generators at full load even under back-water conditions. The stream flow past the plant is extremely variable, ranging from about 1,800 second-ft. minimum to 100,000 second-ft. maximum during a year. At times the head is cut down from 5 ft. to 15 ft. below normal. As shown by tests these generators will readily deliver 7,000 kw. each at 80% power factor. According to a statement made by President Philip Cabott of the Turners Falls company before the Massachusetts Gas & Electric Light Commission, the unit cost of the total development figures $65 per h.p.

Estimated Cost per Kilowatt for two new plants of the Mt. Whitney Power Co. in California are given in Table VII.

TABLE VII. COST PER KILLOWATT FOR MT. WHITNEY PLANTS

Plant	Plant A	Plant B
Capacity in kilowatts	3,500	6,000
Construction equipment, etc.	$10.00	$ 5.00
Power house and miscellaneous buildings	7.10	4.00
Electrical equipment	11.40	10.80
Water-wheels, governors, etc.	8.55	6.65
Pressure pipe line	9.15	13.35
Regulating reservoir	12.90	7.50
Flow lines	45.50	38.90
Diverting dams	1.85	1.50
Total cost per kilowatt	$105.45	$87.70

Plant A	Plant B
Power house: Reinforced concrete, fireproof.	Same as A.
Electrical equipment:	
2-1,750 k.w. generators	2-3,000 k.w. generators.
4-1,250 k.w. transformers	4-2,000 k.w. transformers.
2-55 k.w. exciters.	
3-switchboard equipment, aluminum cell arresters.	Same as A.
Water-wheel equipment:	
Pelton wheels and governor, impulse type wheels.	Same as A.
Head:	
776 ft.	1,325 ft.
Pressure pipes:	
2,680 ft. of 36 in. to 42 in. steel pipe. 5/8 in. to 3/16 in. thick.	3,300 ft. long about same size as A.
Regulating reservoir:	
Excavated solid rock 60,000 cu. yds.	No plans.
Flow line conduits:	
3,300 ft. concrete flume 6 x 3 ft., 6,008 ft. 6 x 4 ft. concrete lined ditch; 1,085 ft. 48 in. x ¼ in. steel pipe siphon practically complete.	2 miles to carry 100 sec.-ft; 6½ miles to carry 50 sec.-ft.; 700 ft. of tunnel. Plans not complete.

Cost of Hydraulic Power Plants of from 100 to 1,000 H.P., and for 10 to 40 Ft. Heads. We have prepared the following formulae for determining the approximate cost of hydro-electric power plants based upon a table of estimated costs given by Charles T. Main in a paper on the "Values of Water Powers" (A. S. M. E., Dec., 1904). By using the formulae the approximate cost of hydraulic operated plants, having horizontal turbines, steel penstocks and walled tail-races (the cost of dam and buildings are not included) may be obtained.

In the formulae, P = horse power of installation; H = head in feet; L = distance from feeder head to end of tail-race.

Where $\frac{P}{H}$ gives a value of from 10 to 100; cost in dollars =

$$625\,(0.9 + 0.001\,L)\frac{P}{H}$$

Where $\frac{P}{H}$ gives a value of from 2 to 10, cost in dollars =

$$700\,(0.9 + 0.001\,L)\frac{P}{H}$$

For example, consider a plant where, $P = 500$ h.p. $L = 400$ ft. $H = 30$.

$$\frac{P}{H} = \frac{500}{30} = 16.66.$$

Cost = 625 (0.9 + 0.4) 16.66 = $13,550.

Take another case where, P = 200 h.p.; L = 200 ft.; H = 40 ft.

$$\frac{P}{H} = \frac{200}{40} = 5.$$

Cost = 700 (0.9 + 0.2) 5 = $3,850.

Cost of 38,000 Kilowatt Development of Yellow Creek, Cal. See the report to the Oro Electric Corporation in Chapter I, under the subject headed "The Calculation of Rates for Electric Current."

Costs per Kilowatt of Installed Capacity, with no "overhead charges," for the Nevada-California Power Co., are given in Table VIII, as determined by the authors in 1913.

Costs per Kilowatt of Four Hydro-Electric Plants. Table IX gives costs per kw. for various plants on the Pacific Coast appraised by the authors in 1911 and 1912. "Physical costs" only are given, the table including no charges for engineering, business management, legal and general expense and interest during construction or brokerage fees.

Comparison of Kilowatt Cost of Steam and Hydro-Electric Power. M. D. Pratt (Engineering News, June 10, 1909) gives the following comparison of operating costs taken from his experience with the plant.

COST OF STEAM PLANT

	Per kw.
Permanent: Ground foundations, buildings, wiring, water supply, coal bunkers, incidentals, engineering and superintendence	$ 35
Boilers, boiler setting, piping, pumps, condensers, heaters, coal and ash handling apparatus, smoke stack and flues, economizers	55
Engines, cranes	30
Generators, switchboard and other elec. app.	30
Total cost per kw. installed	$150

COST OF OPERATION IN ELEC. RY. STEAM PLANT

These are actual figures made by a plant built by the writer and are the results from a full year's operation as shown by the books of the owner:

	Cts. per kw.-hr. on switch-board
Wages	0.1610
Fuel	0.3080
Water	0.0197
Oil and waste	0.0141
Maintenance of boiler plant	0.0210
Maintenance of electric plant	0.0065
Sundry supplies	0.0117
Total cost	0.5420

Interest and Depreciation Charges:

5% interest on total cost of plant	$150 \times .05$	= $7.50
3% Depreciation on Item (a)	$35 \times .03$	= 1.05
10% Depreciation on Item (b)	$55 \times .10$	= 5.50
7.5% Depreciation on Items (c) and (d)	$60 \times .075$	= 4.50
		$18.55

TABLE VIII. COSTS PER KILOWATT OF INSTALLED CAPACITY FOR THE NEVADA-CALIFORNIA COMPANY

	Plant "A"	Plant "B"	Plant "C"
Capacity in kilowatts	6,000	6,000	1,500
Machinery foundations	$1.45	$1.43	$1.19
Crane	.33	.21	1.24
Water wheels, valves, etc.	5.54	5.80	10.32
Governors	.83	1.43	1.30
Generators	6.90	7.68	6.78
Transformers	4.58	4.13	5.74
Exciters	.73	.93	.80
Switchboards, wiring, etc.	1.32	1.75	2.03
Total equipment	$21.68	$23.36	$29.40
Pressure pipes	$19.01	$17.58	$42.23
Flow pipes	10.88	5.21	10.69
Intake dams	6.13	6.75	9.63
Power plant buildings	3.36	2.90	3.40
Total for plant exclusive of overhead costs	$61.06	$55.80	$95.35
Head, intake to nozzles	938 ft	1,111 ft.	425 ft.
Flow pipe length	10,035 ft.	6,426 ft.	3,470 ft.
Flow pipe diameter (wood stave)	48 in.	42 in.	54 in.
Flow pipe grade (ft. per 1,000 ft.)	4	4	4
Pressure pipe length	2,646 ft.	(A) 5,305 ft., (B) 5,575 ft.	4,840 ft.
Pressure pipe diameter (steel)	48 in.	(A) 24 in., (B) 30 in.	42 in.
Water wheels	2 Pelton, 3,600 h.p. 1 Doble, 3,600 h.p. (both 300 r.p.m.)	2 Pelton, 1,500 h.p. 450 r.p.m. 2 Pelton, 3,000 h.p. 400 r.p.m. 1 Doble, 2,850 h.p. 400 r.p.m.	1 Doble, 2,900 h.p. 400 r.p.m.
Governors	2 Pelton, 1 Lombard "Q"	2 Sturgis, 3 Lombard "Q"	1 Lombard "Q"
Generators (2,200 volt)	3 Wh., 2,000 k.w.	3 Allis Chalmers 1,500 k.w. 2 National, 750 k.w.	1 Allis Chalmers 1,500 k.w.
Transformers (O.I.W.C., 30,000 v. to 2,200 v.)	7 Wh., 1,000 k.w.	10 Stanley, 500 k.w.	4 Stanley, 500 k.w.
Buildings	Reinforced concrete	Reinforced concrete	Corrugated iron

TABLE IX. COST PER KILOWATT OF HYDRO-ELECTRIC PLANTS

	Plant "A"	Plant "B"	Plant "C"	Plant "D"
Head	880 ft.	265 ft.	270 ft.	180 ft.
Kilowatts capacity	14,000 k.w.	11,000 kw.	7,000 kw.	1,500 kw. (*f*)
Dams, reservoirs, headworks and bank protection	$9.05	$3.23	$9.76	$2.15
Clearing for flumes and ditches	5.07	...	...	...
Flumes and ditches	23.12	...	9.56	...
Forebays	.80	.95	(*a*) 7.88	1.68
Penstocks	11.09	4.37	4.74	35.57
Machinery foundations	.04	(*b*)	.20	1.09
Waterwheels and governors	3.96	(*c*) 10.30	8.02	18.82
Generators	3.49	(*c*) 8.84	4.72	18.10
Tailraces	(*b*)	...	.51	.40
Exciters	.54	.78	1.67	(*d*)
Switches, switchboards and instruments	2.24	.84	1.32	3.91
Wiring	1.22	1.11	.97	...
Step-up transformers	3.04	3.54	2.35	4.04
Lightning arresters	...	.11	...	...
Cranes	.51	.30	1.28	1.27
Miscellaneous tools and equipment	.90	1.87	1.11	7.98
Wagon roads, railroads and equipment	9.26	.20	3.66	...
Cavity	...	8.38	...	...
Power plant buildings (inc. transformer house)	6.83	.77	4.73	12.92
Miscellaneous buildings, etc. (sheds, offices, residences, etc.)	1.56	2.68	.25	3.86
Miscellaneous charges	.26	.13	...	...
Power plant land, including flumes and road right-of-way	13.18	9.18	14.42	...
Total power plant	$96.16	$57.58	$74.15	$111.79
Transmission line clearing	1.35	5.24	5.24	33.93
Transmission line poles and fixtures	4.89	5.25	5.26	25.27
Transmission line wire and insulators	9.70	8.88	8.89	31.13
Transmission line switches	.79	(*e*)	(*e*)	.07
Telephone line and equipment	.27	.89	.89	4.39
Transmission right-of-way, easements	.08	7.71	7.71	2.16
Total transmission line	$ 17.16	$27.97	$ 27.99	$ 96.95
Total power plant and transmission line	$113.32	$85.55	$102.14	$208.74

(*a*) Forebay large enough for plant triple present size.
(*b*) Included with buildings.
(*c*) Including foundations.
(*d*) Included with generator.
(*e*) Included with other charges to transmission line.
(*f*) Actual development but designed for more.

This should be multiplied by total kw. capacity of plant and divided by total annual output in kw.-hrs., which in the case of the plant mentioned would be:

$$\frac{18.55 \times 2{,}000}{8{,}000{,}000 \times 100} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots .4640$$

Total cost of steam power .... 1.0060 cts.

COST WITH HYDRO-ELECTRIC POWER

Static and rotary transformers would have to be installed to convert the high tension alternating current furnished by the hydro-electric plant to 600 volt d. c. together with necessary switchboard at a cost of	\$37.50 per kw.
(No charge is made for housing or floor space.)	

The cost of operation then becomes:

Wages, reduced one-half	0.0805 cts.	
Fuel, reduced 90% — the remaining 10% being required to maintain steam plant in operative condition and to operate it in short periods	0.0308	
Water reduced 90%	0.0020	
Oil and waste, 75%	0 0035	
Maintenance ½	0.0137	
Sundries ½	0.0058	
Int. and Dep'n on steam plant	0.4640	
		.6003 cts.

To this should be added interest and depreciation on new apparatus, at $5 + 7.5 = 12.5\%$, as follows:

$$\frac{37.50 \times .125 \times 2{,}000}{8{,}000{,}000} = \ldots\ldots\ldots\ldots\ldots\ldots .1172 \text{ cts.}$$

	.7175 cts.
Cost for all steam operation	1.0060 cts.
Difference	.2885

Owing to the 25% loss in transformation as shown in the case of two plants in the writer's knowledge this difference must be decreased in proportion, and we have:

$$\frac{.2885}{1.33} = 0.216 \text{ Cts.}$$

as the highest price that could be paid under the given conditions, without any profit on the transaction.

Total Efficiency of Generation and Transmission of Hydro-Electric Plant of the McCall Ferry Power Company according to a letter in Engineering News, June 10, 1909, from the chief engineer, Cary T. Hutchinson, is as follows:

	Per cent.
Turbines	80
Electric generators	93
Transformers	97
Transmission	92
Transformers	97
Secondary transmission	90
Total efficiency	56

Fig. 5 shows the h.p. resulting from various heads and discharges. The commercial h.p. is that deliverable to customers at a distance and equals the product of the efficiencies given. The rated capacity of this plant is 75,000 kw. at 50% efficiency. The flow required in the Susquehanna River at this point to deliver 75,000 kw. at a load factor of 50% corresponds to an average flow of 37,500 kw.; at a 53-ft. head and 66.5% efficiency the flow required is 12,500 sec-ft.

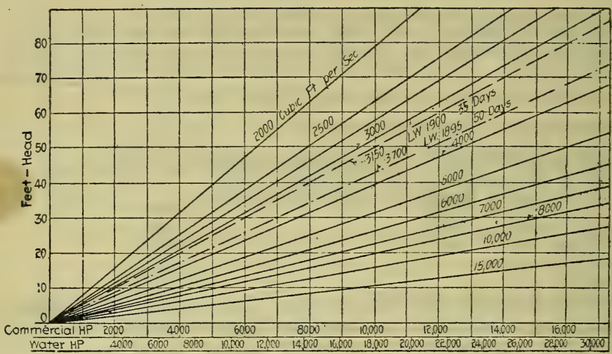


Fig. 5. Diagram showing horsepower resulting from given heads and discharges.

Analysis of Efficiencies of Component Parts of a Hydro-Electric System. Table X gives an outline of the losses and efficiencies, for 1911, of the Seattle Municipal Light and Power plant by J. D. Ross in Engineering and Contracting, Jan. 5, 1912.

The figures given are believed to approximate closely the true values, since great care was taken in the measurements made by frequently calibrated instruments. All results have been checked in as many ways as possible.

The Seattle plant is a hydro-electric system delivering water to two 1,500 k.w. Pelton units and two 5,000 k.w. turbine units under 600 ft. head through two pipes approximately 3½ miles long, one of which is 67¾ and the other 49 ins. inside diam. The current is transmitted at 60,000 volts through 2 lines to Seattle, a distance of 38.7 miles, and is there distributed at 15,000 and 2,400 volts for use by approximately 20,000 customers and for the city street lighting.

Data Necessary in Purchasing Water Wheel. The following data should be furnished manufacturers to aid in the economical design of water wheels:

1. Number of units.
2. Horse power of water wheels.
3. Kw. of generator.

TABLE X. LOSSES AND EFFICIENCIES SEATTLE MUNICIPAL LIGHT AND POWER PLANT (1911)

	Per cent. all-day efficiency.	Average 1911 input, kw.	Average 1911 loss, kw.	Per cent. loss.	Per cent. of pen-stock input.	Per cent. of total loss.
Generating system	54.4	6.009	2,739	45.6	45.6	75.3
Penstocks	97.7	6,009	139	2.3	2.3	3.8
Generating station	55.7	5,870	2,600	44.3	43.2	71.5
Water wheels	60.7	5,795	2,277	30.3	37.9	62.6
Generators	93.5	3,518	227	6.5	3.8	6.2
Exciters	...	76	76	...	1.3	2.1
Station lights and control	...	20	20	...	0.3	0.5
Transmission system	91.6	3,270	276	8.4	4.6	7.6
Step up transformers	96.1	3,270	129	3.9	2.1	3.5
Transmission lines	98.6	3,141	43	1.4	0.7	1.2
Step-down transformers	96.6	3,098	104	3.4	1.7	2.9
Distributing system	79.2	2,994	622	20.8	10.3	17.1
City substation	98.7	2,994	40	1.3	0.7	1.1
S. Lights and control	...	37	37	1.2	0.6	1.0
Switchboard meters	...	....	3	...	0.1	0.1
15,000-volt system	92.5	1,323	90	7.5	1.6	2.7
15.000-volt lines	99.2	1,323	11	0.8	0.2	0.3
15,000-volt transformers	93.2	1,312	88	6.8	1.5	2.4
Series street lights	86.3	305	42	13.7	0.7	1.2
Transformers	95.0	305	15	5.0	0.3	0.4
Series circuits	90.8	290	27	9.2	0.4	0.7
Cluster street lights	79.1	170	35	20.9	0.6	1.0
Cluster transformers	87.8	170	21	12.2	0.3	0.6
Underground cables	90.1	149	15	9.9	0.2	0.4
2,400-volt commercial system	76.2	1.612	357	23.8	5.9	9.8
Feeder regulators	98.6	1,612	20	1.4	0.3	0.6
Primary feeders	96.0	1,592	60	4.0	1.0	1.6
Transformers	88.8	1.532	159	11.2	2.6	4.4
Secondaries	92.9	1,373	89	7.1	1.5	2.5
Customers' meters	97.6	1,284	29	2.4	0.5	0.8
Direct-current system	35.7	77	49	64.2	0.8	1.4
Motor-generator	38.0	77	48	62.0	0.8	1.3
D-c. circuits	95.0	29	1	5.0	...	...
Customers' meters	98.8	28	...	1.2	...	...

	Kw.-hr.	Average
Summary: Total power loss	31,852,500	3,636 kw.
Total power delivered to customers	17,304,900	1,975 kw.
Total power delivered to street lamps	3,481,600	398 kw.
Total delivered power	20,786,500	2,373 kw.

Over-all efficiency, 39.5%

[1 kw.-hr. at the customers' premises requires 1.364 gals. (5,163 liters) of water from Cedar Lake at average head of 590 ft. (179.8 m.)].

4. Total head.
5. Open flume or closed flume.
6. If closed flume, what is number of pipes?
7. What kind of pipe? — wooden stave, steel or concrete?
8. Diameter of pipes.

9. Effective head (unless design of all-water passages to and from wheel is left to water wheel manufacturer).
10. Head water elevation.
11. Floor elevation.
12. Tail water elevation.
13. Head variable, if so, what is normal operating head?
14. If head is variable, what is the range of variation?
15. How important is power and economy at lowest head?
16. Speed of generator, if already decided.
17. If speed of generator is not decided, name speeds which seem to purchaser most desirable and ask recommendations.
18. Flywheel effect of generator.
19. What speed regulation is desired for different load changes?
20. Will units run in parallel with other plants? If so, give general characteristics of such plants.
21. If running in parallel with other plants, can these plants be used to regulate the system?
22. What is the character of load factor?
23. What is the nature of water (silty or clear)?
24. What date shipment of material is desired.
25. Advise if it is expected that manufacturer shall furnish governor.
26. Give sketches of power plant site.
27. Give information as to what is to be expected in the way of guarantees.
28. Give any other information which you think would influence the design of the wheel.

The following data should be supplied to the purchaser by the manufacturer:

1. A check of the calculation on effective head.
2. Horse power guarantee at normal head.
3. Guarantee at other heads, if head is variable.
4. Speed guarantee, including runaway speed.
5. Recommendation for best speed if same has not been determined.
6. Speed regulation guarantees.
7. Efficiency guarantees at full load, ¾ load and ½ load.
8. Point of greatest efficiency of wheel and value of same in per cent.
9. Efficiency guarantees for available head conditions.
10. If water wheel manufacturer furnishes governor, give information as to the type, make, power required to operate same, also what variation in speed will not be exceeded before the governor will begin to readjust gates to meet a change of load, either gradual or sudden.
    In what time will governor completely open or close gates?
    Within how many seconds will the speed of the unit be restored to normal?
11. Complete drawings showing machinery proposed.

12. Complete description of machinery proposed.
13. Guarantee of durability.
14. Guarantee of shipment.

Cost of Water Wheels and Turbines. The data and costs in Table XI have been obtained in connection with some of the appraisal work of the authors.

TABLE XI. HORIZONTAL IMPULSE WHEELS

Rating in h.p.	Head in ft.	Rev. per min.	Weight in lbs.	Cost f.o.b. factory
100	365	600	3,500	$ 515
100	1080	625	3,200	727
1,500	1080	450	.....	3,100
2,500	275	300	49,100	11,232
2,850 *a*	1080	400	24,000	5,557
2,850 *b*	1080	400	26,000	5,361
2,900	365	400	.....	9,949
3,000 *b*	1,080	400	.....	5,530
3,200 *c*	175	200	.....	17,100
3,530	900	300	29,000	4,955
3,600	900	300	.....	6,699
3,600 *b*	900	300	40,000	6,960
3,600 *b*	900	300	47,500	8,605
3,600 *b*	900	300	67,000	8,900
5,000	450	225	126,000	19,250

(*a*) Includes governor, probable weight 5,000 lbs., cost $1,400.
(*b*) Includes governor and gate valve.
(*c*) Includes governor and exciter wheel.

TABLE XII. TURBINE WHEELS

No.	Rating in h.p.	Head in ft.	Rev. per min.	Weight in lbs.	Cost f.o.b. factory
1.	1,000	40	200	.....	$10,500
2.	1,200	85	360	.....	12,000
3.	3,000	365	400	52,250	8,230
4.	3,200	90	277	.....	22,500
5.	10,000	275	300	.....	32,410
6.	10,000	275	360	380,000	28,000

1. Parallel flow, double runner, horizontal — price includes 700 kw. generator, exciter and governor complete.

2. Parallel flow, double runner — price includes 2 12-in. 875 r.p.m., exciter wheels, 2 tachometers, 2 48-ft. steel draft tubes and 2 governors.

3. Price includes:

Item	Probable segregation of cost
Turbine, 43 in.	$4,740
Governor	1,400
Relief valve	200
Tachometer	80
2 gauges	10
Draft tube	50
36 in. gate valve	1,750
Total cost	$8,230

4. This was a very complete installation — price includes turbine with governor, relief valve, bursting plate, etc., tachometer, spare runner, etc.

5. Radial inflow type, axial discharge.

6. Francis type horizontal, price includes turbine, governor, etc., complete. The cost of installation of this unit is as follows:

Turbine, complete	$28,000
Foundations	1,260
Installation	1,395
Extras	2,725
Freight	3,460
Total cost	$36,840

Cost of Horizontal Water-Wheels. Table XIII is from Bull. No. 5 (Feb., 1916), Office of State Engineer, Salem, Oregon. The costs are estimates based on figures obtained from two independent manufacturers of hydraulic machinery, and are for water wheels, in place, not including relief valves or other accessories, but do include freight charges and cost of installation.

TABLE XIII. COST OF WATER-WHEELS, IN PLACE

Horse power	Head in feet	R.p.m.	Cost erected
1,085	32	200	$10,000
2,187	58	300	10,500
2,320	60	360	10,400
2,650	65	360	11,000
2,860	70	360	15,000
3,470	90	400	10,400
3,500	87	400	10,000
3,760	92	400	12,000
4,090	100	514	10,000
4,091	300	400	25,000
4,300	135	450	21,000
4,500	132	450	22,000
4,720	138	450	22,000
4,736	140	450	22,000
5,400	132	400	22,300
6,496	210	400	24,000
7,091	280	400	27,000
9,091	400	360	31,000

Steel Penstocks — Water Pressure and Weight. R. A. Wright (Engineering News, Feb. 10, 1910) gives the following data:

Determination of Size. The principal factors may be outlined as follows: (1) the quantity of water to be delivered to the power plant, (2) the head on different sections of the penstock, (3) the length of the penstock, (4) the nature of the application of the power, (5) accessibility of the site, (6) the design fixed upon for the wheels.

The first factor is determined, usually, as one of the first essentials of the installation, being one of the factors upon which depends the feasibility of the development. Whether the water to be delivered is conveyed by one or more penstocks depends on the quantity of water and the number of units fixed upon for the

plant, but this is a question belonging to power-house design and will not be discussed here. The quantity of water having been settled, the size of penstock is fixed by the speed at which it is allowed to run, and this is a point, as stated above, which it is impossible to determine by rule in all cases. A high speed entails considerable loss of head by friction with a consequent low efficiency of the installation as a whole, while a slow speed brings increased cost of construction of the penstock itself. Considering the head, we find that under a low head it is advisable to use a slow speed because the loss of a foot of head by friction is a much larger percentage of the total head than where a high head is available, and because the spouting velocity, and consequently the rim speed of the turbines, being low, the water should enter the wheel case at a comparatively low speed in order to secure the best efficiency. Under a high head a slight friction head is not a serious matter and it is better for the efficiency of the wheels that the water should reach them at rather a high speed. In the nature of things, however, it is usually found that longer penstocks are required for high heads than for low.

Of course, the friction head increases with the length of penstock so that lower speeds are more desirable for long penstocks than for short ones, other things being equal. The question of water-hammer becomes increasingly important with long penstocks and high speeds because of the great mass of water to be accelerated and retarded, and the greater fluctuations of speed. This may be taken care of to a certain extent by the use of stand-pipes or relief-valves, and certainly one or the other of these should be provided on all except the shortest penstocks, but it is well, also, to keep down the speed of water, this being the surest safeguard of all. Consideration should be given to the conditions under which the plant is to operate — pulp grinders, for instance, run continuously at full gate-opening, while turbines supplying power for electric railways may operate normally at half gate, only opening up wide to take care of an occasional, momentary peak load. In the latter case it would be fair to base the calculation of friction losses on the quantity of water consumed by the wheels at half gate.

The use to which the power is to be applied also has a bearing on this question. For instance an electric power plant, being subject to possible variations from full load to no load instantaneously, would require a larger penstock than a plant using the same quantity of water for driving a number of wheels connected to separate machines, as pulp grinders, and not subject to an instantaneous variation of so large a percentage of the whole power. The type of wheels used may also have a certain influence in the determination of the most desirable speed of water since impulse wheels require a high speed at the entrance to the wheel while reaction wheels require a lower speed. With the scroll-case type of turbine the water enters at nearly the speed of the entrance edge of the wheel buckets or at such a fraction thereof as will be determined by the shape and arrangement of the guide vanes, while such a

speed in the case of a cylindrical wheel-case, inclosing, say, a pair of wheels with central draft-tube and the inlet at the side of the case, would set up such eddies as might bring down the efficiency of the plant 50%. Of course it is always possible to change the speed of the water gradually by means of a tapered section of penstock just before entering the wheel-case, either increasing or decreasing the speed to suit the requirements of the wheel, but care must be taken to make such changes very gradual or else an appreciable loss of head will result. Though it is impossible to fix general rules for definite speeds, it is worth while to classify the speeds as characterized by common practice. Low speeds are from 2 to 8 ft. per sec.; medium speeds are from 8 to 12 ft. per sec.; and high from 12 to 25 ft. per. sec.

The accessibility of the site may be an important factor in determining the size of the penstock since the erection and transportation of a large penstock may amount to a prohibitive figure, while the probable market for power may be only a fraction of the available power, in which case it would be economy to permit a considerable loss of head by friction in order to reduce the size of the penstock. It will be seen that for the intelligent solution of this problem we require complete information as to the flow of the stream, topography of the site, probable market for the power and financial resources of the promoters. These questions, of course, are fundamental to the proper solution of any power proposition and will have been carefully investigated as the very first step in determining the feasibility of the development.

A little thought leads to the conclusion that, in a given water power development, the most economical size of pipe to install is the one with which the annual costs and charges plus the value of the energy loss in the pipe is a minimum. The size of pipe that most nearly meets this requirement can be found by cut and try methods, though there is a wide latitude of interpretations to the expression "value of energy loss in the pipe." When the head and quantity of water are fixed within narrow limits, as noted before, the solution is greatly simplified. Mr. A. L. Adams, M. Am. Soc. C. E., in a paper before the American Society of Civil Engineers, June 5, 1907, demonstrated:

"That pipe fulfills the requirements of greatest economy wherein the value of the energy lost in frictional resistance equals four-tenths (0.4) of the annual cost of the pipe."

Many have claimed that this rule has no rigid application, but it is logical and in absence of other determining factors should be employed.

In a hydro-electric plant it may be advisable to compute the size of pipe in this way at the prevailing load, developing the peak load at smaller efficiency. Some designers, on the other hand, may prefer to establish the size of pipe from an estimate of the value of the all-day losses or the average efficiency of operation. In the rare cases when a waterfall is being developed to obtain the greatest possible power and where the cost of installation therefore has only a minor bearing, Mr. Adams' rule cannot have any bearing.

Table XIV gives the friction heads corresponding to different speeds of water in penstocks from 2 to 10 ft. in diameter and 100 ft. long, based on a formula given by Merriman.

TABLE XIV. FRICTION HEADS OF RIVETED STEEL PIPES

Diam. in.	Velocity in ft. per sec. 5	6	7	8	9	10	11	12
24	.348	.488	.645	.820	1.005	1.200	1.405	1.620
30	.264	.369	.485	.615	.755	.900	1.050	1.210
36	.297	.288	.380	.480	.585	.700	.812	.930
42	.166	.231	.304	.383	.466	.575	.670	.765
48	.136	.189	.256	.322	.392	.485	.562	.640
54	.121	.167	.228	.286	.348	.430	.500	.570
60	.104	.151	.198	.258	.314	.388	.450	.515
66	.095	.132	.180	.225	.274	.339	.392	.467
72	.084	.121	.164	.207	.251	.297	.360	.410
84	.069	.100	.130	.170	.206	.255	.295	...
96	.058	.084	.109	.142	.181	.213	...	...
108	.050	.071	.098	.121	.153	...	...	...
120	.043	.061	.084	.109	...	...	...	...

Formula (Merriman) $Hf = f \frac{L}{D} \frac{V^2}{2g} = 1.55 f \frac{V^2}{D}$ for $L = 100$

Where Hf = loss of head due to friction, L = length of pipe in feet, D = diameter of pipe in feet. V = velocity of water in ft. per sec., g = acceleration of gravity, f = a factor.

In calculating the above table f was taken 10% greater than the values recommended by Merriman to allow for the roughness due to rivet heads and for the lap of circumferential seams.

Weight of Penstock. Having fixed on the size of penstock we next come to the question of fixing the thickness of the shell to suit the pressure of water to be carried. Most penstocks are constructed of tank-steel plates having a tensile strength of from 45,000 to 50,0000 lbs. per sq. in., although for high heads and speeds it is advisable to use the best quality of flange steel. The riveting is done in all styles, single and double-riveted joints being most common, although triple-riveted lap and butt joints are occasionally used. A number of considerations affect the choice of a style of riveting, but it would be safe to say that a majority of penstocks are built with all lap seams, the circumferential seams being single-riveted and the longitudinal double-riveted. This gives a sufficient excess of strength in the circumferential seams to provide for the bending between supports. For heads under 30 ft. all seams may be single riveted, making the spacing in the circumferential seams as great as consistent with securing a tight joint.

Having selected a style of riveting and quality of plate, thus determining the unit strength, we are able to fix on the thickness of plate to be used. In this connection Table XV will be of use, giving the maximum heads under which various thicknesses of plates should be used with various diameters of penstock. The table is based on a fiber stress of about 7,500 lbs. per sq. in. under static load, which is an average figure for ordinary conditions,

The table gives values for both single and double riveting based on nominal efficiencies of 60 and 70% respectively. Where more efficient seams or other values of fiber stress are used the head can be obtained by simple proportion.

TABLE XV. MAXIMUM PERMISSIBLE HEADS ON STEEL PENSTOCKS, IN FEET

Diam. ins.	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8
			SINGLE RIVETED — EFFICIENCY 60%					
30	130	175	220	260	...	...	...	...
36	110	145	180	220	...	...	...	...
42	90	125	155	185	220	...	...	...
48	80	110	135	165	190	...	...	...
54	70	95	120	145	170	190	...	...
60	65	85	110	130	150	175	...	...
66	60	80	100	120	135	160	180	...
72	55	75	90	110	125	145	165	...
78	...	70	80	100	120	135	150	165
84	...	65	75	95	110	125	140	155
96	...	...	70	80	95	110	120	135
108	...	...	60	70	85	95	110	120
			DOUBLE RIVETED — EFFICIENCY 70%					
36	130	170	210	260	...	...	...	...
42	110	145	180	215	260	...	...	...
48	95	130	160	190	220	...	...	...
54	80	110	140	170	200	220	...	...
60	75	100	130	150	175	205	...	...
66	70	95	120	140	160	185	210	...
72	65	90	110	130	145	170	195	...
78	...	85	100	120	140	160	180	195
84	...	75	90	110	130	145	165	180
96	...	...	80	95	115	130	145	160
108	...	...	70	85	100	115	130	140

Table XVI gives the weight of the penstock per lineal foot for either single or double riveting and for various thicknesses of plates. In figuring this table allowance was made for the circumferential seams, based on the most usual width of plates for the different thicknesses, also for over-weight of plates according

TABLE XVI. WEIGHTS PER FOOT STEEL PENSTOCKS (EMPTY)

SINGLE RIVETED

Diam. ins.	3/16 in. Pl.	1/4 in. Pl.	5/16 in. Pl.	3/8 in. Pl	7/16 in. Pl.	1/2 in. Pl.	9/16 in. Pl.
30	72	97	116	137	...	...	...
36	86	116	140	165	...	...	...
42	99	135	163	192	222	...	...
48	113	154	187	220	254	...	...
54	127	172	210	248	286	326	...
60	141	191	234	276	318	361	...
66	155	210	257	304	350	396	448
72	170	228	280	332	382	432	488
78	...	246	303	360	414	467	527
84	...	264	326	388	446	502	566
96	...	...	373	444	510	573	646
108	...	...	420	500	575	645	726

DOUBLE RIVETED

Diam. ins.	3/16 in. Pl.	1/4 in. Pl.	5/16 in. Pl.	3/8 in. Pl.	7/16 in. Pl.	1/2 in. Pl.	9/16 in. Pl.
36	89	120	145	171	...	...	...
42	102	139	168	198	229	...	...
48	117	159	193	227	261	...	...
54	131	177	216	255	294	335	...
60	146	196	241	284	326	370	...
66	160	216	263	312	359	406	458
72	175	234	287	340	391	442	499
78	...	253	310	369	424	478	538
84	...	270	334	398	456	504	578
96	...	...	381	454	520	585	659
108	...	...	428	511	586	658	740

to the manufacturers' standard table of allowances. The weights given in the table, of course, are for straight pipe — for bends an additional allowance should be made, up to 10% for bends of short radius, on account of the narrow plates used which makes the allowance for circumferential seams an increasing factor.

Cost of Steel Penstocks. The following unit costs were taken from Bull. No. 5, Office of the State Engineer, Salem, Oregon (1916).

Steel Work: Item.	Price per pound f.o.b. works
Trash racks (Bessemer steel rails)	$0 015
Fabrication and placing	0.02
Freight and haulage (depending on locality)	....
Total (not including freight and haulage)	$0.035
Penstocks:	
Steel plate	$0.0175
Fabrication and placing $0.0325–$0.0375)	0.0350
Freight and haulage (depending on locality)	.....
Total (not including freight and haulage)	$0.0525

Cost of Concrete Penstock. The following is from "Design and Construction of Hydro-Electric Plants" by R. C. Beardsley.

At Charles City, Ia., Mr. Beardsley built a reinforced concrete penstock, 1,100 ft. long with a capacity of 18,000 cu. ft. per min. The section was a compound arch 12 ft. 3 ins. in height and 20 ft. wide at bottom. The concrete was 8 ins. thick at center of top and bottom arches and about 2 ft. thick at the haunches, the whole being heavily reinforced. Forms were constructed in sections 12 ft. long with 5 ribs per section. The 15 sections built made 182 ft. of penstock. The outer forms were made of 2-in. surfaced plank and 6- to 8-in. posts, on 4-ft. centers.

The costs for the first 182 ft. with penstock resting on solid rock were as follows:

	Cost per lin. ft.
Forms, inner, making	$ .67
Forms, erecting	.57
Lumber at $30 per M. ft. b.m.	1.08
Steel, placing and hauling	.22
Cement, 5½ sacks	3.00
Dowel pins	.09

	Cost per lin. ft.
Sand, 0.61 cubic yards at $0.50	.30
Labor, mixing, tamping, etc.	.83
Concreting rock bottom, labor	.80
Washing inside	.07
	$7.63

	Cost per cu. yd.
Concrete, labor, mixing, tamping, etc.	$ 1.36
Concrete, cement, 7 sacks	4.40
Concrete, sand, 1 cu. yd.	.50
Forms, making and erecting	2.00
Forms, lumber	1.80
Steel, 90 lbs. at $1.83	1.65
Steel, placing	.28
Steel, hauling	.13
	$12.12
Placing steel per lb. (upper and lower)	$.003

The second 182 ft. of penstock cost $10.75 per cu. yd. As each 182 ft. section was built the cost of the inner forms was decreased. Also, the men became accustomed to the work and did it more cheaply.

Where the penstock rested on piers, the cost was as follows:

	Cost per lin. ft.
Part above bottom	$5.80
Bottom	2.17
Piers 18 in. thick and average height 30 in.	1.00
	$8.97

	Cost per cu. yd.
Forms, lumber	$0.36
Forms, labor at $2	.27
Concrete, labor	1.14
Concrete, cement, 6 sacks	3.30
Sand	.50
Steel, placing	.27
Steel, 175 lbs. at $1.83	3.20
	$9.04

In the above work the bottom was difficult to get to, hence the high cost of labor on concrete.

The intake at the inlet of penstock contained 59 cu. yds of concrete and 5,000 lbs. steel. The form work was quite difficult, consisting of floor, beams and 10-in. walls.

The cost of concrete was as follows:

	Cost per cu. yd.
Forms, labor	$1.00
Forms, lumber	0.00
Concrete, labor	.78
Concrete, cement, 7 sacks	3.85
Concrete, sand	.50
Concrete, washing and trimming	.15
Steel, 85 lbs. at $1.83	1.56
Steel placing,	.26
	$8.10

A reinforced concrete abutment 140 ft. long and about 16 ft. high cost per yard, as follows:

	Cost per cu. yd.
Forms, labor	.96
Forms, removing and trimming	.23
Forms, lumber (old)	.00
Steel, 45 lbs.	.82
Steel, placing	.10
Cement	3.30
	$5.41

Cost of Concrete and Brick Penstocks. R. C. Beardsley prepared the diagram for the cost per ft. of circular concrete penstocks shown in Fig. 6. He states that the data from which this curve is plotted were derived largely from "Cost Data," by H. P. Gillette, but also from numerous other sources.

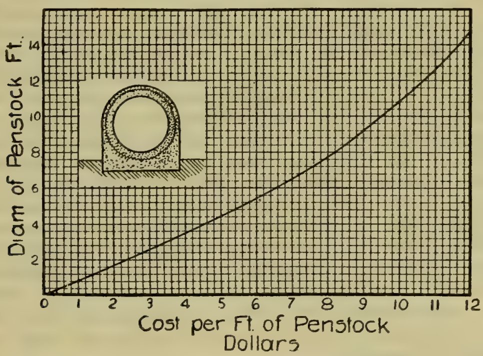


Fig. 6. Cost of concrete penstocks.

Reinforcing costs about three cents per pound for steel, and 0.5 cent to install. The concrete costs about $10 per cubic yard, including every item. Round rods cost about $34 per ton.

He further states that brick penstocks require 570 bricks per cu. yd. and 1.25 bbls. of cement. A mason should lay 1,200 bricks in 8 hrs. at a cost of $6.

Wood-Stave Pipe for Water-Power Penstocks. Robert E. Horton (Engineering Record, March 20, 1915) states that as a result of experience gained, in some cases through costly failures, the conditions under which durability of wood-stave pipe may be best attained are now well known. The staves must be completely and continuously saturated; they should be perfectly sound and of the very best material; and the fibers of the wood must not be injured or broken in erecting the pipe by over-cinching or drawing the bands too tight.

Experience has shown that in the majority of cases, except where

pipe is buried in soils containing acids or strongly alkaline groundwaters, the durability of the bands is greater than that of the staves. For durability, the bands should be as large as is compatible with securing watertightness of the pipe and at the same time avoid crushing of the fiber underneath the bands. The same conditions as to quality of material and coating of the bands apply as in the case of steel pipe if durability is desired.

Where large steel pipes are used under low pressure a certain minimum thickness of metal must be used to provide stiffness, and as a safeguard against rapid development of leakage at rust spots. For very large thin pipes stiffening rings are also added to prevent excessive deformation of the pipe by its own weight. In the case of continuous wood pipe the economical thickness of staves required for structural reasons and to secure watertightness is usually sufficient to provide adequate stiffness.

In wood-stave pipe, as in steel, the pressure is resisted entirely by metal. In the case of wood-stave pipes with bands having rolled threads or upset ends the full strength of the metal can be developed to resist tension. In the case of riveted steel pipe, especially for low heads, a large amount of metal is required in excess of that needed to resist tension due to water-pressure. From considerations of economy in erection the riveted joints used for low pressures have generally relatively low efficiencies, so that only a fraction, varying commonly from 40 to 65% of the strength of the metal in the pipe walls, is available to resist pressure.

These conditions indicate an important field of usefulness for wood-stave pipe for waterpower penstocks or portions of penstocks which are of large diam. and under relatively low heads. As the head increases, the joint efficiency which can be commercially realized in steel pipes is increased, and the percentage of metal added for other than tension purposes is decreased, so that for heavy pressures the amounts required in wood-stave and steel penstocks would approach equality.

The conditions determining which of these two types of penstock will be most efficient and economical in a given case are: Relative first cost or investment; relative durability; relative cost of repairs and maintenance; relative carrying capacity or, more properly, relative power output with conduits of a given size.

The relative cost must, of course, be determined for each specific case. Large steel penstocks in the Eastern States commonly cost from 3.5 to 5 cts. per lb., erected, exclusive of cradles or other supports. No simple general rules for estimating the cost of continuous wood-stave pipe can be given. The materials are mostly obtained from the Pacific Coast and formed staves at the mills cost from about $30 to $35 per M. ft. b. m. for Douglas fir, to $45 for red-wood.

Freight is a large element in determining both the cost of wood-stave pipe and the relative economy of wood and steel. In general, the advantage of stave pipe over steel increases, proceeding westward from the Eastern States owing to reduced freight rates on wood and increased freight on steel.

Steel conduits are commonly supported on concrete cradles, though sometimes buried or partly buried in earth. The cost of woodstave conduits is materially affected by the method of support. Support on timber trestles is usually the cheapest. For large pipe above ground concrete cradles are preferable and the cost and spacing are about the same for wood-stave and steel pipes.

Experience has shown that the staves of continuous wood-stave pipe are least durable when partially buried or when buried in porous soils, such as sands or gravels. Wood pipe is perhaps the most durable when buried below the line of saturation of the soil or in compact clay soils, where the pipe surface will be kept constantly moist by the prevention of evaporation of seepage through the staves.

Conditions where the pipe can be buried below ground-water level are very rare and in such cases the cost of unwatering the trench during pipe construction is likely to inhibit the use of this method. Again, pipe cannot be buried where there is rock at the surface and if buried in the soil under conditions otherwise favorable for durability, the bands will be destroyed rapidly if the ground-water is either strongly alkaline or contains humic acid from the decay of surface vegetation, as is commonly the case in woods. The pipe is not accessible to repair when buried and while it is apparently necessary to bury wooden pipe in some instances as a protection against landslides in mountainous regions, yet in the majority of cases wood-stave pipe should not be placed underground unless the conditions are all favorable and even then only when a calculation, based on economical considerations, gives a result in favor of placing the pipe underground.

TABLE XVII. COST OF WOOD PIPE

	On cradles	Buried
Cost of pipe per foot	$13.60	$15.50
Cost cradles or trench	6.40	1.50
Total investment	$20.00	$17 00
Life, years	40	15
Repairs, per cent. per year	1	0
ANNUAL CHARGES		
Interest, at 6 per cent.	$ 1.20	$ 1.02
Depreciation		
At 2½ per cent	0.50	....
At 6⅔ per cent	...	1.134
Repairs	0.20	0.00
Total annual charges per feet	$ 1.90	$2.154

As an illustration the calculation in Table XVII is given, in which it is assumed that the life of the buried conduit without repairs would be 15 yrs., whereas its life above ground, properly maintained and repaired, would be 40 yrs.

The comparison given is for pipe 9 ft. in diameter under an

average head of 60 ft. It is assumed that the pipe above ground is supported by concrete cradles. This increases the first cost per foot materially over that for the buried pipe, but even then, owing to the rapid depreciation of buried pipe, the calculations show the total annual charges per foot of pipe to be considerably less for the pipe supported above ground.

It is generally conceded that the carrying capacity of new wood-stave pipe with a given friction loss is somewhat greater than that for new riveted steel pipe. There is some diversity of opinion as to the amount of difference. The writer believes that the later formulae for the capacity of these two classes of pipe are substantially correct, and that there is a material difference in favor of wood-stave pipe when new as compared with steel when new. Of the two, steel pipe is also subject to much the greater increase in friction head or decrease in carrying capacity with increased age. Probably the Hazen and Williams formula represents the best determination of the carrying capacity or friction head for steel pipes. The Moritz formula is probably the best available for application to large wood-stave conduits. In a somewhat later review of the experiments, Andrew Swickard gives the formula

$$n = (D/30{,}000) + 0.0105$$

where n = coefficient of roughness to be applied in the Kutter-Chezy formula, and D is the inside diameter of the pipe, in inches. (Engineering and Contracting, Jan. 6, 1915, p. 70.) This formula is convenient for those who prefer to work from the Kutter formula or diagrams based thereon.

For pipes 9 ft. in diameter, with velocities of 6 ft. per second, the friction head is as follows:

Riveted steel pipe, Hazen and Williams formula, with $C = 110$, friction head 1.06 ft. per thousand.

Riveted steel pipe 10 yrs. old, Hazen and Williams formula, with $C = 100$, friction head 1.26 ft. per thousand.

Wood-stave pipe, Hazen and Williams formula, with $C = 120$, friction head 0.9 ft. per thousand. With the Moritz formula the friction head equals 0.60 ft. per thousand.

The friction loss by the Moritz formula is considerably less than by the Hazen and Williams formula. The two results may be reconciled in some degree by considering that Moritz's formula applies to new pipe properly constructed and in the best condition, whereas friction head given by the Hazen and Williams formula would, in the writer's opinion, only apply to average pipes in service as heretofore constructed, many of them being improperly constructed and in some cases subject to deposits of sand and sediment in the pipe inverts. Even when free from sediment and properly constructed the carrying capacity of wood-stave pipe may be reduced somewhat by growth of slime and spongilla on the interior surface, which slightly decreases the effective diameter and increases friction by throwing off small eddies, although not decreasing the apparent smoothness of the surface.

In comparing the merits of steel and wood pipe conduits for

specific cases, the relative carrying capacities should be taken into consideration, as illustrated by the example which follows. The relative cost or value of conduits of different materials having different degrees of roughness is sometimes arrived at by estimating the difference in cost of conduits of different sizes but which will carry equal quantities of water with the same total loss of head. In the writer's opinion this method is not generally applicable in the case of conduits for power purposes. In such cases there is usually a maximum permissible velocity determined by conditions of speed regulation or governing. Economy dictates that whatever material is used, the fixed maximum velocity should be equalled but not exceeded. Accordingly the conduit should be of the same diameter, in the majority of cases, regardless of the material or friction loss per foot of length. If the velocity is the same in both and the friction loss in wood-stave is less than in steel pipe at the given velocity, the average net head available at the power plant will be greater if the wood-stave pipe is used, and the market value of the average increase in power so obtained is one of the items to be considered in determining the relative economic value of the two types of conduits.

The gain in power should be estimated from the increase in head available with the plant operating at its average load, not at its maximum load. The power gained by reduced friction in the conduit is obtained at very little expense. The power and speed of the turbine are increased by increased head. Generator costs are smaller per unit at the higher speeds and there would be no material difference in attendance or overhead charges in the two cases. Instead of calculating the gain in marketable power due to increased head as clear profit, it is perhaps safer to estimate the value of the increased power pro rata the same as the value of the average power output of the plant.

Table XVIII shows a comparative estimate of the cost of wood-stave and steel penstocks each 9 ft. in internal diam, and 2,000 ft. long. The figures are based on recent bids for a conduit in central New York. In this case the computation shows some apparent economy in favor of wood-stave pipe regardless of increase in power. It will be noted that taking into account the increase in power, the result of such a calculation may indicate that it is an economical advantage to use wood-stave pipe even where the first cost is equal to or a little greater than that for steel pipe.

In the case on which the figures given are based, wood-stave pipe was not used in spite of the economic showing in its favor, because of the general feeling of uncertainty then prevalent regarding the durability and conditions tending to produce long life for wood-stave pipe. It is highly desirable that the conditions governing the durability of wood-stave pipe should be more generally understood and accepted: First, to prevent repetition of serious mistakes of the past, where wood-stave pipe has been used under conditions to which it was not well adapted. Second, to prevent its rejection in cases where it clearly shows a decided economical advantage over steel.

TABLE XVIII. COST OF WOOD AND STEEL PIPE

	Steel pipe	Wood stave pipe
First cost of pipe	$17.40	$13.60
Concrete cradles	6.00	5.00
Total investment	$23.40	$18.60
Life assumed	40 yr.	30 yr.
Depreciation rate	2½%	3⅓%
Repairs	0.5%	1%
ANNUAL CHARGES PER FOOT OF PIPE		
Interest and taxes at 7%	$1.638	$1.302
Depreciation	0.585	0.620
Repairs	0.117	0.186
Total	$2.340	$2.108
Total for 2,000 ft. conduit	$4,680	$4,216
Value of power gained, 25 h.p. at $10 per h.p.-year	00	250
Annual balance	4,680	3,966
Net saving with wood pipe	.....	$714
Capitalized saving at 8%		$8,925

Thickness of Staves. Complete and perpetual saturation of the staves being the prime requisite, to secure durability care should be taken that the thickness of the staves is not too great in proportion to the pressure. If durability is desired, wood-stave pipe should not be used unless it will be continually filled with water under static pressure head of at least 20 to 30 ft. The staves are made from stock sizes of timber and their exact size and thickness for a particular case are governed by the smallest commercial size of board from which the stave can be cut. This is best determined by an accurate full-size drawing of the stave section. Thickening the staves increases the stability of the pipe against deformation and generally is conducive to water-tightness at the joints or seams. The staves should not be so thick as to prevent a reasonable amount of percolation through the pores of the wood under pressure. To meet these conditions the following formula was devised by the writer for the use in preliminary determination of stave thickness:

$$T = 1 + h/100 + d/100$$

where T = thickness of staves in inches; h, head in feet; d, diameter of pipe in inches. It is believed that staves determined by this formula will have the maximum of durability consistent with reasonable stiffness of the pipe.

Decay of Wood Pipes. (Bull. 155, U. S. Dept. of Agriculture.) Decay of pipes exposed to the atmosphere and free from contact with the soil almost invariably starts at the ends of staves, as a result of leaky joints. Where water leaks out and runs down over the outside of the pipe favorable conditions are afforded for the growth of algae; then mosses may begin to grow in the soil that collects on such spots, and decay spreads to adjoining staves.

Bruising the staves in handling or injuring them by too tight cinching of bands renders them more susceptible to infection by the spores of wood-destroying fungi, thus hastening decay. The life of exposed pipes may be prolonged by promptly stopping all leaks as they develop and by keeping the exteriors dry. The decay of buried pipes has also in some instances been arrested by removing the covering and leaving them exposed.

The asphaltum or tar coating applied to machine-banded pipe, while intended primarily as a protection against corrosion of the bands, doubtless helps also to some extent in preserving the wood. Until recently the practice has been to leave the ends of wooden sleeve couplings untreated. These couplings almost invariably decay long before the main pipe. This may indicate that infection by wood-destroying organisms starts principally where the coating is absent, though less perfect saturation of the wood in the sleeves may be the more largely responsible for the early decay, as it may also be noted that decay occurs at summits of pipe lines, where air accumulates, much sooner than at depressions.

Cost of Woodstave Penstocks. E. H. Warner in describing the hydraulic plant of the Puget Sound Power Co. in Pierce County, Wash., gives the following data:

There are 345 lin. ft. of built up wood pipes. Woodstaves were cut from 2-in. × 6-in. clear lumber dressed to radial lines with a circular curve inside and out and have oak tongues in the butt joints. Round iron bands, ⅝ in. in diameter, coated with asphalt composition hold the staves in place. The bands are spaced 8-in. centers, except at the butt joints, where the spacing is reduced to 4 ins. Two concrete walls within the embankment enclose the pipe and extend 2 ft. above. This work was let by contract at $2.96 per lin. ft. for 48-in. pipe, and $1.47 per lin. ft. for 18-in. pipe.

The total cost of development approximates $125 per h.p. A portion of this is properly chargeable to preparation for a second installation, which, when made, will reduce the cost of the entire development to approximately $90 per h.p.

Cost of Timber Flume for Water Power in British Columbia. C. A. Lee (Engineering and Contracting, Nov. 11, 1915) states that the power development of the Vancouver Island Power Co. required 5.3 miles of timber flume along a steep and broken side hill. Figure 5 shows the plans of this structure built, and gives all essential dimensions and details except as noted in the statements following. The T-bent shown was used only for "intermediate bents" under 12 ft. high between two standard bents. Generally the trestle was low, averaging not over 7 ft. high, but at a few gulch crossings it had two or more decks. The alinements, following this natural contour, was a series of curves, some as sharp as 90 degs.; no serious retardation of the water resulted. Wier measurements indicated for this flume a value of 122 for *c* in Chezy's formula $V = C\sqrt{rs}$. In locating the flume each bent finding was decided and the bent dimensions were computed. From these notes the saw mill at the lower end of this flume cut to lengths all bent members with daps and gains complete. A

service railway along the flume line delivered the sawed material. About 5,000M ft. b. m. of lumber were required, or a little less than 1,000M ft. b. m. per mile of flume. Not including hauling or clearing, the cost of lumber in flume was $17.41 per M. ft. b. m., and all lumber was cut at the company's mill and logged from the company's land. The total cost of the flume, excluding again hauling and clearing, was $419.27 per 100 lin. ft., or, say, $4.20 per lin. ft.

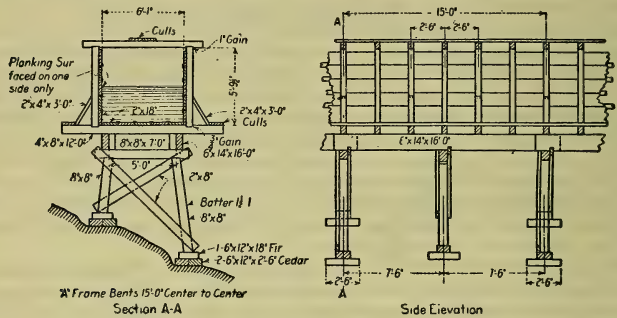


Fig. 7. Timber flumes for Jordan River power development, British Columbia.

The Economics of Pipe Line Diameters. A discussion of a method for determining economical pipe line construction is given by Mr. C. W. Harris in a paper which we reprint here from the Proceedings of the Pacific Northwest Society of Engineers. (See Engineering and Contracting, Aug. 27, 1913.) While the discussion is developed with specific relation to pipe lines for water power plants, some of the conditions are general and apply to pipe lines for water supply and irrigation.

When the engineer is investigating a power proposition and has reached the point where he wishes to decide on the diameter of the penstock, three questions might be logically presented to his mind in the following order:

(1) What is the smallest size of pipe through which a given amount of power may be transmitted?

(2) What is the smallest diameter which can be used without exceeding allowable velocities?

(3) What is the economical diameter of penstock when proper consideration has been given to the value of the water right?

Any one of these considerations may be the controlling point and fix the size of the penstock. The first question will probably control in long pipes if the value of the water used is small The second will control in short pipes under the same condition of water value. The third will control in either long or short pipes when the value of the water is considerable.

Smallest Pipe. Returning to the first question, it is evident that smallest possible pipe is the one which must work at its maximum capacity. The problem may, therefore, be restated as follows without changing its meaning. What is the condition for maximum amount of power which may be transmitted through a pipe of known

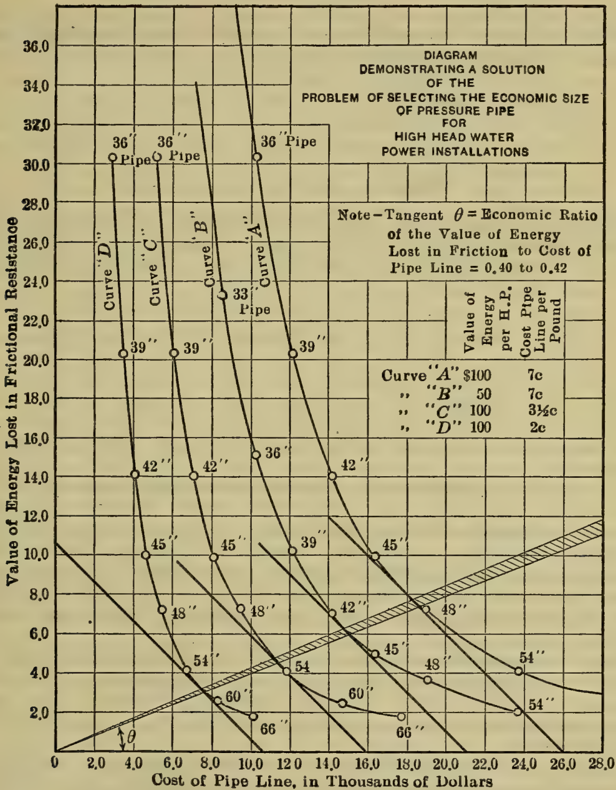


Fig. 7A.

diameter when the total available head is fixed and the quantity of water is unlimited? This is now in the form of an old familiar problem, the solution of which is as follows: If there were no loss of head by friction, greater quantity of water would, of course, imply greater power since the effective head would remain constant. ($H.\ P. = Qwh. \div 550.$) But a greater quantity must be accompanied

by a greater velocity with corresponding loss of head and hence a loss of power. Calling this lost head h', the horsepower delivered by the pipe $= qw(h - h') \div 550$ but the friction head

$$h' = \frac{fl}{d}\frac{v^2}{2g} \quad \dots\dots (1)$$

making the power delivered in foot pounds (which we shall call energy and denote by a large E)

$$E = Qwh - Qw\frac{fl}{d}\frac{v^2}{2g}$$

$$= Qwh - \frac{Q^3wfl}{a^2 2gd} \quad \dots\dots (2)$$

a being the area of the pipe. To determine the conditions for maximum power delivered by the pipe, it is necessary to equate the first derivative of the above expression to zero. The first derivative of E with respect to Q

$$\frac{dE}{dQ} = hw - \frac{3Q^2wfl}{a^2 2gd} = u \quad \dots\dots (3)$$

$$\therefore h = \frac{3\,fl}{d}\frac{v^2}{2g} = 3h' \quad \dots\dots (4)$$

The second derivative is negative which is the condition for a maximum.

It will here be noticed that placing the first derivative equal to zero makes our total head equal three times the head lost by friction, and means that the pipe is delivering its maximum amount of energy when the friction loss is one-third of the total head. The answer to our first question, therefore, is as follows: the smallest pipe which will deliver a given amount of power with a given total head is the pipe which will cause one-third of that head to be lost in friction.

Thus in temporary developments such as contractor's plants or plants in isolated districts with large power possibilities and limited demand, a pipe may be chosen of such diameter that when the maximum power is being developed, one-third of the total head is lost in friction.

One caution which must not be overlooked is that the reduction of effective head should not unduly increase the cost of the turbines to generate the required power. Working close to the limit must also be accompanied by judgment concerning possibility of variation of friction factor for pipe and for possible reduction of efficiency of turbine at overload.

A small factor of safety is introduced in the above investigation, however, because of the fact that our investigation assumes the head loss by friction to vary as the square of the velocity, whereas, for a constant friction factor for smooth pipes the head varies at a

slightly less rate. Using the exponential formula recommended by Messrs. Saph and Schoder,

$$H = .38\frac{v^{1.86}}{d^{1.25}} \qquad (5)$$

the maximum power is delivered when the head lost is .35 of the total head.

Penstock Velocities. The answer to the second question does not belong in a paper of this character. The greatest allowable velocity in penstocks has been subject to many discussions and a great many different opinions have been offered. The points which must be consulted in settling this important question generally defy mathematical analysis excepting where full conditions of operation are known. They have to do principally with such problems as dynamic action at sharp curves and with water hammer during regulation of load. We will, therefore, leave this question to a subsequent paper or to the judgment of the engineer. The answer does not affect what is to follow in this paper excepting to fix limits beyond which we cannot apply our results.

Economical Pipe. We will now turn to the third and most important question (the economical size of the pipe). It is very apparent that when either the smallest possible pipe is used, or when the pipe is limited in size by excessive velocity, the friction head will be large and the power must be obtained at a sacrifice of water. This may be objectionable or may not be objectionable, depending upon whether the water has commercial value or has no commercial value, water being considered valueless only when there is at all seasons of the year a surplus after the demand for power is supplied.

When the demand for power exceeds the supply, undeveloped water under head has at once a commercial value which should be approximately equal to the difference between selling price of power and cost of production where the cost of production includes interest, depreciation, cost of operation, etc. A loss of one-third of the total head (the condition which gives the smallest pipe) or even a loss of sufficient head to produce excessive velocity will require an excess of valuable water to produce the required power. Thus our third question shapes itself as follows: what is the diameter of pipe which results in the most economical production of power, that is, what are the conditions for minimum cost of delivering power to the turbines?

The quantity to be placed at minimum must include two separate items, (1) the yearly cost of pipe (interest, and depreciation), (2) the yearly cost of the power wasted by friction. The second factor depends upon the quantity of water, head lost by friction and the value of a horsepower year. This phase of the problem was quite thoroughly treated in a discussion aroused by Mr. A. L. Adams in an article entitled, "A Solution of the Problem of Determining the Economic Size of Pipes for High-Pressure Water Power Installation," in the Transactions of American Society of Civil Engineers,

Vol. LIX., page 173. This paper and the discussions dealt only with high head pressure pipes in which the thickness of pipe for constant head would have to vary with the diameter, making the cost of pipe for a given head (and, therefore, the yearly cost of pipe line under that head) to vary as the square of the diameter. We will give a simple solution arriving at the same conclusion as did Mr. Adams and then extend the investigation to other conclusions.

$$C = Kd^2 \quad \dots\dots (6)$$

where C equals yearly cost of pipe, d the diameter, and K is some constant depending upon the cost of steel per pound, interest, depreciation, etc., but to which no particular value need be given for present purposes.

The power lost by friction varies as the head lost h' and the quantity of water Q. But

$$h' = \frac{fl}{d}\frac{v^2}{2g} \quad \dots\dots (7)$$

$$\therefore Qwh' = Qw\frac{fl}{d}\frac{v^2}{2g} = \frac{Q^3}{2ga^2}\frac{fl}{d} = \frac{Q^3 16fl}{2g\pi^2 d^5} \quad \dots\dots (8)$$

Therefore, for a constant quantity Q the

yearly value of power consumed by friction $= k'd^{-5}$.

And since the

annual cost of pipe lines $= kd^2$,

the function to be placed a minimum is

$$u = kd^2 + k'd^{-5} \quad \dots\dots (9)$$

$$\frac{du}{dd} = 2kd - 5k'd^{-6} = 0 \quad \dots\dots (10)$$

$$\therefore 2kd^2 = 5k'd^{-5} \quad \dots\dots (11)$$

$$\text{or } \frac{2}{5}kd^2 = k'd^{-5} \quad \dots\dots (12)$$

Two-fifths annual cost of pipe line = yearly value of power consumed by friction.

This result is the one suggested by Mr. Adams and the method is somewhat similar to that used in a number of discussions of his paper. The conclusion to be drawn is that the proper diameter of pipe is that which will make two-fifths of the annual cost of the pipe equal the cost of the power lost by friction.

This is, therefore, the answer to our third question when applied to large riveted steel pipes under high head.

Although the article of Mr. Adams considered only the question of high pressure pipe lines and, therefore, pipe lines in which the thickness for any given head would necessarily vary directly with

the diameter, there seems to be no good reason why a similar investigation should not be made for pipes of constant thickness. In fact, it seems just as important to obtain correct diameter of pipes under small head as to obtain correct diameter of pipes under large head, especially in as much as a large majority of power plants with long penstocks are so constructed that the greatest length of penstocks is subjected to very low pressures, the pipe dropping quickly as it approaches the power house. Under this condition, the greatest total cost is for a portion of the pipe line which, though thin, is much thicker than that computed for static head (with proper factor of safety). These pipes are constructed with a specified minimum thickness and until this is exceeded, the thickness of the pipe is constant and the cost of the pipe will vary as the first power of the diameter instead of the second power as in the above example,

$$\text{yearly cost of pipe line} = kd$$

But as the friction loss is independent of the pressure, the value of the power lost by friction is the same as that in the previous case. This change in the law of the variation of pipe cost has the effect of changing the function for minimum to

$$u = kd + k'd^{-5} \quad \text{(13)}$$

$$\frac{du}{dd} = k - 5k'd^{-6} = 0 \quad \text{(14)}$$

$$\text{or } kd = 5k'd^{-5} \quad \text{(15)}$$

$$\therefore \frac{1}{5} kd = k'd^{-5} \quad \text{(16)}$$

But kd is now the cost of the pipe and kd^{-5} is the same as before, (i. e., the value of power lost in friction). Therefore, the result shows that the proper diameter of the pipe is that which will make one-fifth of the cost equal the value of the power lost by friction.

Thus it is seen that the ratio of cost of lost power to cost of pipe is only one-half as great in the second case. This, of course, does not mean that twice as much may be spent for pipes of constant thickness. But it does mean that some additional expenditure should be made under this second condition, which expenditure will give somewhat increased diameter and thereby decrease the amount of power lost until the above relationship is established.

Nor is the above treatment necessarily confined to these two simple cases. If the cost of the pipe does not vary as the second power, nor exactly as the first power, we need not conclude that the law of variation is no longer exponential. As long as the cost of pipe can be expressed as a constant times the diameter raised to any constant power, the above treatment can be applied. Under this condition

$$\text{Annual cost of pipe} = kd^n.$$

The function to be placed a minimum is therefore

$$u = kd^n + k'd^{-5} \quad \ldots\ldots (17)$$

$$\frac{du}{dd} = nkd^{n-1} - k'd^{-6} = 0 \quad \ldots\ldots (18)$$

$$\therefore -kw = k'd^{-5} \quad \ldots\ldots (19)$$

$$\text{or } \frac{h}{5} kd^n = k'd^{-5} \quad \ldots\ldots (20)$$

This means that the correct diameter of pipe is that which makes

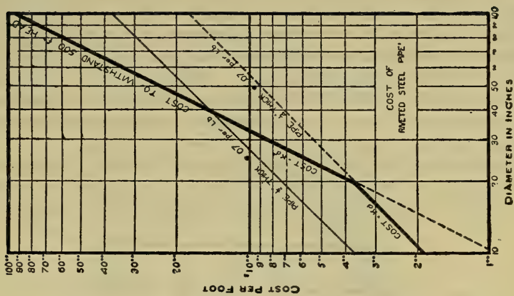
n fifths of anual cost of pipe = cost of lost power.

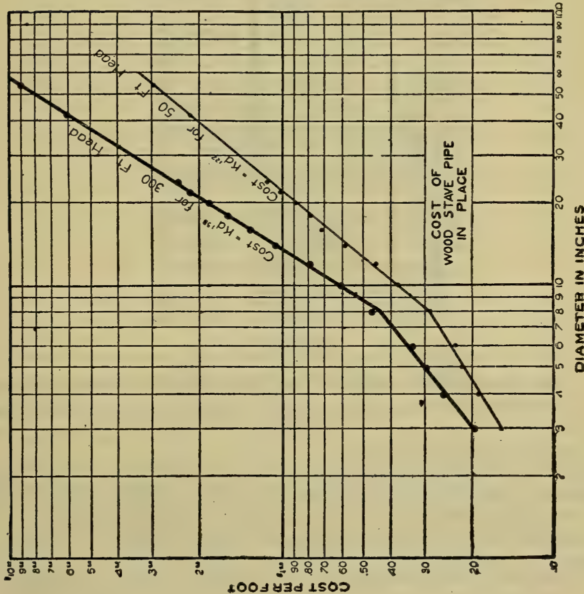
n is found from the relation of cost to diameter (for a constant head) as expressed above, n being the index of the power in kdn.

The above case, of course, includes the other two cases, since the value of n may be 2, as in the first case, or 1, as in the second case. Or it may include all of the cases where n lies between these two values or exceeds them. The condition will always be that for minimum cost with values of n greater than 1, the case with which we are concerned. The application of the result is not even complicated by this general form of the statement. It is believed that the mixed values of n present cases more of a practical nature than the two apparently more simple cases mentioned previously. For example, the cost of high pressure steel pipe cited in the first investigation must be combined with all the accessory costs (if they do not remain constant with the different diameters of pipe). These costs do not necessarily vary with the same power of the diameter as does the cost of the simple pipe. Thus the total cost will no longer vary as the exact second power. Another important case offering this apparent difficulty is that of the wood-stave pipe. The cost of wood-stave pipe (as related to its diameter) follows an exponential law in the ordinary case. But the value of the exponent is generally greater than 1, and yet smaller than 2.

Fortunately, the exact value of the exponent n can always be determined by logarithmic plotting. The cost of various diameters of pipe being plotted as ordinates with the diameters as abscissae, the tangent of the slope of the line is the value of n.

The use of the logarithmic sheet brings all cases to a common basis. Even those in which the index of the power is not exactly constant may be treated by this method since in the limits of any one problem, the variation of n is insignificant. Fig. 8 shows the entire variation of n for wood-stave pipes under 300 ft. head to be from 1.00 for 4-in. pipes to 1.58 for 54-in. pipes and practically that entire variation occurs at one point where the type of construction changes. (The lower value of n is for such small pipe and applies to so few commercial sizes that we may safely exclude them when dealing with wood pipe.) Fig. 9 for steel pipes, shows this same characteristic variation in n occurring at the diameter requiring increased thickness for the particular head for which the curve is drawn. The value of n for steel pipes changes abruptly from 1 to 2 at this point as the value of n changes from 1 to 1.58 for wood-stave pipes. For our present purposes we are chiefly concerned with the fact that (above this critical point) the exponent n is constant for all diameters as long as the head is constant.


COST OF
RIVETED STEEL PIPE
DIAMETER IN INCHES
COST PER FOOT
COST TO WITHSTAND 500 FT HEAD
COST = Kd
.07 per Lb
PIPE ¼" THICK
PIPE ⅛" THICK


COST OF
WOOD STAVE PIPE
IN PLACE
DIAMETER IN INCHES
COST PER FOOT
Cost = Kd for 300 Ft Head
Cost = Kd for 50 Ft Head

Figs. 8–9.

The exponent for wood pipe also changes with variation of head on the pipe. For example: Cost of pipes under very low head increases almost directly in proportion to the diameter, which means that the exponent is but slightly above 1. On the other hand, for very high heads, the cost increases almost as the square of the diameter placing the other limit of the exponent at 2. Between these two values, the variation is shown to be as represented by Fig. 10. These results were obtained by plotting actual cost of pipe as in Fig. 8 and are sufficiently accurate for application to practical cases.

In computing the economical diameter by use of these exponents, the diameter is not sensitive to small variations in exponent. In view of this fact and also anticipating the fact that the diameter

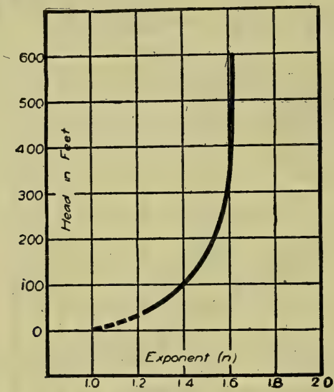


Fig. 10.

of any one pipe line should not vary throughout its length excepting for moderately high heads, we are justified in using a single value of 1.5 for all heads between 50 ft. and the greatest head found practical for stave pipe.

It is the writer's belief that an investigation involving these exponents is justified in the large majority of cases. This simple check will then eliminate the possibility of a false minimum being found graphically or algebraically by reason of local variation of points not located near the minimum. Much time may also be saved, providing the computor is familiar with his logarithmic sheet. For example, Fig. 11 shows the simple method of determining the proper diameter when the law of variation is known. This plate is constructed for high head steel pipe carrying 100 cu. ft. per second and subjected to the following heads: 125 ft., 250 ft., 500 ft., 1,000 ft. and 2,000 ft. One point was computed for actual annual cost at ten per cent. interest and depreciation, with steel at seven cents. The line was drawn with the proper slope (2 because

the pipe is steel) and the other four lines drawn with the same slope through points which increased in proportion to the head. Another point was computed for a check and the whole work was complete. This set of lines represents the actual cost of pipe for various diameters for all the foregoing heads. Another line is now drawn which represents two and one-half times the power lost by friction at $25 per h.p. The intersections indicate the correct diameter for their respective heads.

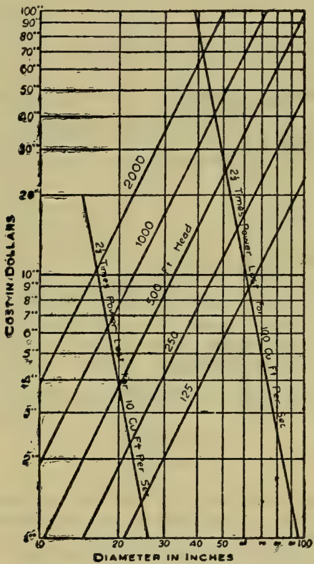


Fig. 11.

Even this operation is longer than necessary. We might compute the proper diameter for one head and knowing the law of variation of diameter with respect to head, construct the line which will give us the proper economical diameter for any head (same pipe or same quantity). For determining the law of variation of diameter with respect to head for the economical adjustment of steel pipe, we refer back to the expression for cost.

Annual cost of pipe for constant head $= kd^2$.
Annual cost of pipe for constant diameter $= k'h$.
Annual cost of pipe for varying head $= k''hd^2$.
Value of power lost $= kd^{-5}$.
Therefore, $k''hd^2 = ckd^{-5}$.
Where c is a constant 5/2 for the particular case at hand.
Therefore, $h = kd^7$ where k is still another constant.
From which $d = kh$-1/7.

This means that the diameter of steel penstock for high heads (of varying thickness) varies inversely as the 7th root of the head. To show that this is correct, we will take the data from Fig 11 and construct Fig. 12, with diameters as ordinates and heads as abscissae. The resulting line checks the above conclusion. It slopes downward to the right indicating inversely, and the slope is 1 to 7 indicating the 7th root. The line might, therefore, have been just as easily drawn after computing one point.

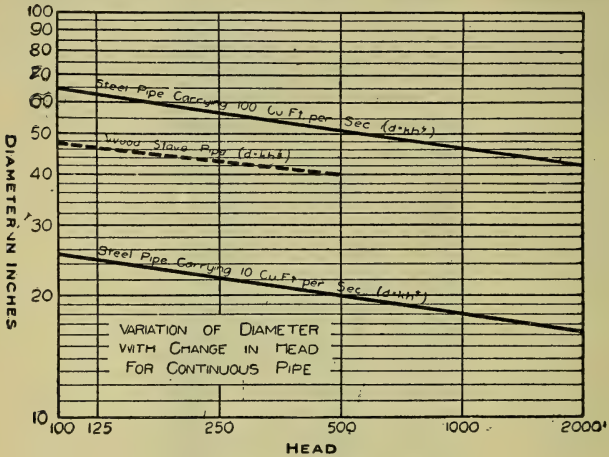


Fig. 12.

Even this operation need not be confined to the theoretical or the special case. The law of variation of cost when both head and diameter are considered may be expressed

$$\text{Cost of pipe} = Kh^m d^n.$$

The value of n has already been determined for a wood-stave pipe. m can be determined in a similar manner by plotting on logarithmic sheet. This logarithmic sheet is not shown, but the results of m for various heads (a mean of several diameters variation being small) are shown on Fig. 13.

These results combined with those on Fig. 3 give all the information necessary to determine the proper relation between diameter and head for wood-stave pipe.

If...... $kh^m d^n = Ck'd^{-5}$ .... (21)

$h^m = kd^{-5+n}$ .... (22)

$d = kh^{-\frac{m}{5+n}}$ .... (23)

or...... $d = kh^{-\frac{1}{x}}$ .... (24)

where k is an unknown constant and x is the exponent of h representing the law of variation of d.

Fig. 14 shows values of x for various values of h. It will be seen that large values of x indicate small changes in diameter of pipe and vice versa, and when x is equal to infinity the diameter is constant for all heads (note that this comes from value of $n = 1$, the case for cost of pipe varying directly as diameter as in the case of steel pipe with constant thickness).

The diameter not being sensitive to small changes in x, we may safely say that for heads under 100 ft. the pipe should remain

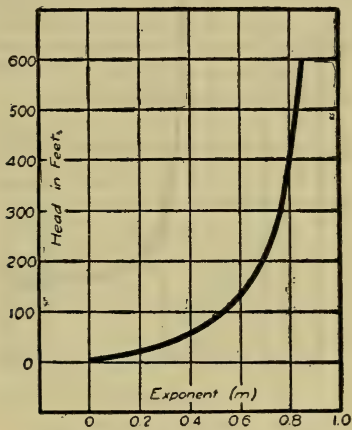


Fig. 13.

constant diameter its entire length regardless of head. And we can just as safely say that for heads above 100 ft. and within the range of application of wood pipes, a constant value of x may be taken. The mean value 9 from Fig. 14 is correct for all practical purposes. Therefore, for wood pipes 100 ft. head or more, the diameter should vary inversely as the 9th root of the head.

The operation of Fig. 11 was repeated for wood pipes on the assumption that all wood-stave pipes under pressure increase in cost (and therefore have their yearly cost increased) as expressed by the following

$$\text{Annual cost of pipe} = kd^{1.5}$$

The diameters for various heads were then plotted and the slope found to be 1/9, thus verifying the previous conclusion.

This law of variation for diameters with respect to head is now applicable to any pipe line under varying head regardless of value of water right and regardless of what use is made of the water.

It means that for a given quantity of water and total loss of head, this particular variation of diameter will give the cheapest pipe.

To show that this investigation is justifiable and not a mere theoretical hair splitting, take the following illustration.

Let it be required to conduct 100 cu. ft. per second economically through 10,000 ft. of wood-stave pipe. Suppose the first half of the pipe is subjected to 100 ft. head and the remaining half to 300 ft.

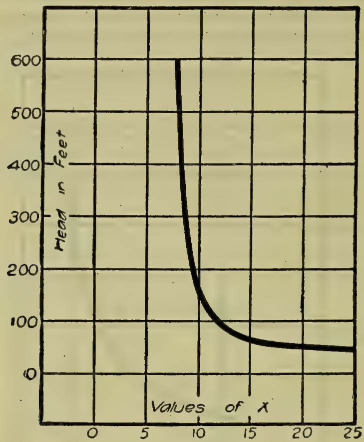


Fig. 14.

head. If after sufficient study it is found that 60 ft. is a permissible loss, a too common practice would be to use a 42-in. pipe throughout the entire length. This pipe would cost the following amount:

5,000 ft. of 42-in. pipe for 100-ft. head at $2.95	$14,750
5,000 ft. of 42-in. pipe for 300-ft. head at $6.09	30,450
Total	$45,200

But our rule says that the second half of this pipe should be smaller because it is under greater head and that the ratio of the two diameters (for wood pipe) should be 1:31/9. This ratio is 1/1.13, which is the ratio of a 40-in. to a 45-in. pipe, and this combination of pipes gives practically the same friction loss. But the cost now is:

5,000 ft. of 45-in. pipe for 100-ft. head at $3.20............	$16,000
5,000 ft. of 40-in. pipe for 300-ft. head at $5.60	28,000
Total	$44,000

Thus it is shown that there is a saving of $1,200, which is 2½ per cent. of the total cost of the pipe.

To show this is not a mere local variation let us take other combinations, 66-in. and 37-in., for example, which makes the total cost \$52,250, or even 54 and 38, which costs \$46,600, or the reversing of the correct combination making 45 and 40, which require a cost of \$47,250.

These results plotted to scale with ratio of diameters abscissae (see Fig. 15) show minimum cost to be plainly for the ratio 1.13 which was originally chosen. In conclusion the following points may be summarized:

(1) It is allowable to use the smallest possible pipe line for power when the water consumed has no value. This smallest pipe is the one which with a friction loss of one-third of the total head will deliver a quantity of water sufficient to produce the required power with the other two-thirds of the total head.

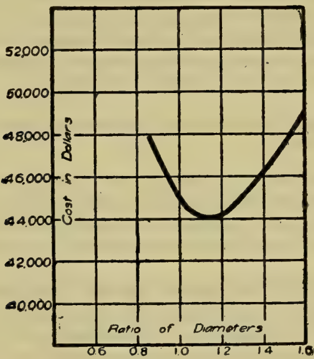


Fig. 15.

(2) If a pipe line is subjected to a varying head throughout its length, but the cost for any particular diameter remains constant for those various heads, the diameter should also remain constant throughout; but if the cost of the pipe is different for the different heads, the diameter should be smaller for the larger head. The correct diameter under any particular head is that which will make $n/5$ of the cost of the pipe for a given length equal to the capitalized value of the power consumed by friction in that same length, n being 2 for steel pipe and 1½ for wood-stave pipe, and for any pipe takes the index of d in the expression.

$$\text{Cost} = kd^n.$$

With this diameter determined under one head, the diameter of the same pipe under any other head should vary inversely as the 7th root of the head if the pipe is a high-pressure steel pipe, or as the 9th root of the head if the pipe is wood-stave.

(3) If the quantity to be delivered is fixed, and the available

friction loss is also fixed, as is the case with a pipe line connecting two reservoirs of fixed elevations, the diameter of the pipe should vary throughout the length of the same laws expressed above, the head to which the pipe is subjected being the static head for which the pipe is designed.

Authors' Comment. One of the laws deduced by Mr. Harris may be stated thus:

The diameter of a steel penstock for high heads (i. e., a "pressure pipe") should vary inversely as the seventh root of the head.

Mr. Harris also proves that for a wood stave pressure pipe the diameter should vary inversely as the ninth root.

Unfortunately the text of the article is considerably marred by a rather careless use of two important words—"value" and "cost." In fact, Mr. Harris uses these words indiscriminately, and he attaches to the word "value" a meaning that really makes it synonymous with profit. Unfortunately the conclusion is of a sort that might lead a young engineer entirely astray, as may be readily shown. Mr. Harris proves that the most "economic" (= profitable) diameter of penstock is secured when:

"Two-fifths annual cost of pipe line equals yearly value of power consumed by friction."

As stated by Mr. Harris, this law was previously deduced by Mr. A. L. Adams. Search of the text of Mr. Harris' article discloses the fact that the word "value," as used in this law, means the profit derived from the sale of water power, for he says:

"When the demand for power exceeds the supply, undeveloped water under head has at once a commercial value which should be approximately equal to the difference between the selling price of power and cost of production, where the cost of production includes interest, depreciation, cost of operation, etc."

Even this statement is not precise, for the "commercial value" of a water power is the *capitalized* annual profit derivable from it, and not the annual profit.

A correct statement of the Adams law of pressure pipe diameter would be as follows:

The most profitable diameter of pressure pipe is secured when two-fifths the annual cost of the pipe (exclusive of excavation and anchorage) equals the annual profit that might be derived from the energy consumed in pipe friction.

In applying this law care should be taken to use the word profit in a proper sense. Profit is the difference between gross income and cost. Cost includes interest, depreciation, taxes, repairs and operating expenses.

Care should also be taken to multiply the energy lost in pipe friction by the efficiency of the power generating machinery; and, if the power is sold after transmission, the efficiency of transmission and transformation should also appear as a factor.

Finally, if refinements are desired, consideration must be given to the fact that in a pressure pipe designed for peak load condi-

tions there will be much less loss of energy due to friction under *average* load than under peak load.

In solving an illustrative problem, Mr. Harris makes use of logarithmic paper in an interesting manner, but his text does not agree with the chart, for the text speaks of plotting the annual cost of the pipe, whereas the chart shows its first cost. The text omits giving the *length* of the illustrative pipe line. It also speaks of the "value" of the power lost by friction as being $25 per h.p. Certainly the profit is rarely as much as $25 per h.p. year, whereas the *value* (i. e., capitalized annual profit) of water power is usually much more than $25 per h.p.

CHAPTER X

FIRST COST AND OPERATING EXPENSES OF COMPLETE ELECTRIC LIGHT AND POWER PLANTS

Cross References. For a general discussion of the operating costs of an electric lighting plant, see the latter part of Chap. I. For data on depreciation, see Chap. II. See also Steam Power, Chap. VII.

Graphical Analysis of Operating Costs into Fixed and Variable Expenses. Arthur Jobson, Electrical World, April 14, 1917, says: For a given power plant operating under normal conditions the unit cost of generating electric energy varies inversely as the kilowatt-hour output. When the total monthly or yearly operating expense is assumed to vary directly as the output, and uniformly therewith, the expression for the unit cost may be represented by

$$U = a/F + b \tag{1}$$

in which U is the cost in cents per kilowatt-hour, F the plant factor in per cent. (*i.e.*, the ratio of the mean load for any period of time to the aggregate generator rating multiplied by 100), and a and b constants.

If $R =$ aggregate generator rating in kilowatts, $h =$ number of hours operated, and $C =$ operating expense in dollars during the period of h hours, then, substituting in equation (1), $C = [(a/F + b) \times h \times F/100 \times R] \div 100$, or

$$C = hR(a + bF)/10^4 \tag{2}$$

In this expression $hRa/10^4$ represents the fixed operating expense in dollars for the period considered, and $hRbF/10^4$ represents that part of the operating expense varying with the station output.

From these relations it may be seen that if the actual unit production costs are available and the unit costs are made to conform with equation (1), the total operating expense may be separated into two components, one component being the fixed operating cost and the other that part of the operating cost varying directly with the kilowatt-hour output. The relative proportions of these costs will be characteristic of the particular type of plant and the conditions under which it may have been operating during the period covered by the analysis. This method of analysis is not only applicable to the total operating expense, but any part of such expense, as, for instance, the determination of the relative proportions of the fixed and variable expense required for fuel used in operation.

Applications of this graphical method of analysis to actual data obtained from the operation of a small electric plant are represented in Figs. 1, 2 and 3. The small circles platted in Figs. 1 and 2 indicate average monthly switchboard production costs in cents per kilowatt-hour for the year 1915 and the first ten months of 1916 respectively. Fig. 3 applies similarly to the cost of fuel in the operation of the same plant. The unit cost curve xy in Fig. 1 was determined in the following manner:

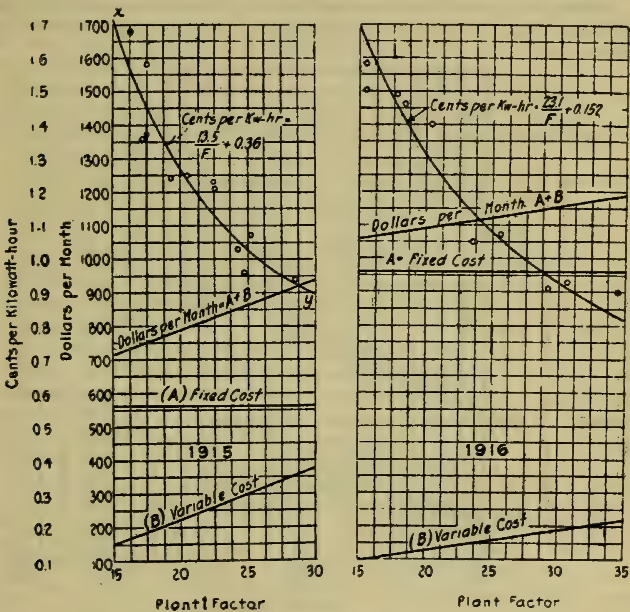


Fig. 1. Fig. 2.

Figs. 1–2. Cost of energy delivered to the switchboard at different plant factors.

The 12 months of the year were divided into 2 groups, one group consisting of the 6 months having the lowest unit production costs, and the other group including the 6 months of highest similar costs. For each group the number of hours, kilowatt-hours generated and operating expense in dollars were totalized. From these the average unit cost and corresponding plant capacity factor in per cent. were obtained for each group. These values determined the location of two points on the mean unit cost curve xy, and thus permitted calculation of the constants a and b in equation (1), after which the curve was plotted as shown. The corresponding curves

in Figs. 2 and 3 were determined in a similar manner. Equation (2) was then used to determine the average monthly variation in operating expense for corresponding plant factors within the range of the station output in kilowatt-hours. These expenses are represented in the chart by means of straight lines.

Space does not permit a very thorough discussion of these curves. They indicate a relatively larger component of fixed operating expense than would be expected, even for the cost of fuel. It may be pointed out that the total expense in dollars does not include such fixed charges as interest on the investment, depreciation, in-

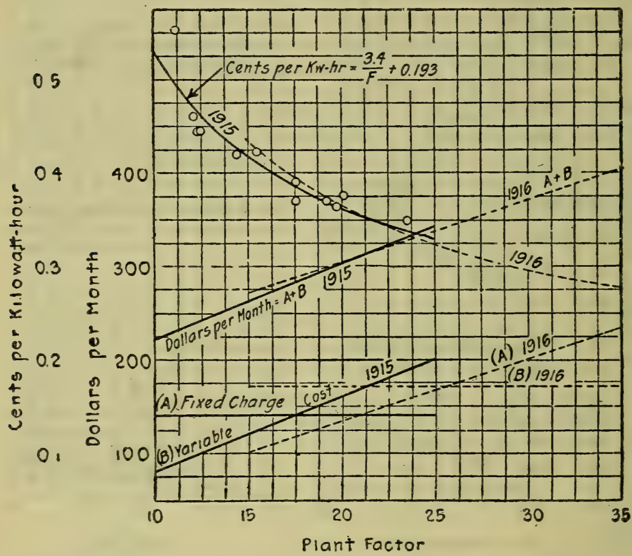


Fig. 3. Cost of fuel with different plant factors.

surance, etc. The excessive fixed operating expense during the first ten months of the year 1916 may be attributed partly to the higher wages paid both for operation and maintenance and in part to a larger expenditure than is necessary under ordinary conditions for replacements.

Output of Large Generating Systems. Table I from Electrical World, April 7, 1917, shows the peak load, date of same, yearly output in kw.-hrs. and yearly load factors of the largest generating systems of the country.

Relation of Peak Load to Capacity. The following figures relate to steam-electric plants and were compiled from the reports of officials of the companies.

Edison Electric Illuminating Co., of Boston. From 1905 to 1914 the rated plant capacity increased from 35,400 kw. to 116,400 kw. with the average 74,255 kw. The peak load increased from 26,311 kw. to 65,092 kw., average 45,852 kw. The ratio of peak to capacity ranged from a minimum of 54.8% in 1909 to a maximum of 74.4% in 1905, the average being 63.3%.

Mobile Electric Co., Mobile, Ala. From 1909 to 1912 the rated plant capacity was 3,595 kw. and the peak load increased from 2900 to 3190 kw., the average ratio of peak to capacity being 85%. In 1913 and 1914 the rated plant capacity was increased to 6,595 kw., the peak load being 3150 and 3081 kw. for the 2 yrs., thus bringing the average ratio down to 47% for that period.

Muskogee Gas & Electric Co., Muskogee, Okla. The rated plant capacity was 4,600 kw. from 1912 to 1914. The peak load was 3,000, 2,300, and 2,200 kw. during that time, thus making the ratio of peak to capacity 65, 50 and 48%.

Oklahoma Gas & Electric Co., Oklahoma City. In 1912, 1913 and 1914 the rated plant capacity was 5,650 kw.; the peak load 3,864, 3,467, and 3,480 kw.; the ratio 68, 61 and 62%.

Ottumwa Railway and Light Co., Ottumwa, Ia. From 1908 to 1914 the rated plant capacity was 1600 kw.; the peak load averaged 1380 kw. with a minimum of 1175 kw. in 1909 and a maximum of 1720 kw. in 1913; the ratio averaged 86, minimum 73, maximum 107.

San Diego Consolidated Gas & Electric Co., San Diego, Cal. The average rated plant capacity was 4,720 kw. from 1906 to 1914, it being 1,220 kw. in 1906 and 12,470 kw. in 1914; the average peak load was 3,195 kw., increasing from 918 kw. in 1906 to 7,075 kw. in 1914. The average ratio, peak to capacity, was 68, the minimum being 57 in 1914 and the maximum 116 in 1908.

The Edison Illuminating Company of Detroit. From 1905 to 1914 the rated plant capacity increased from 13,200 kw. to 90,500 kw.; the peak load from 10,300 kw. to 83,300 kw. The ratio averaged 81%, being 62% in 1908 and 100% in 1906.

Union Gas and Electric Co., Fargo, S. D. The rated plant capacity was 1,860 kw. from 1911 to 1914. The peak load averaged 1551 kw. and the ratio 84%.

Commonwealth Edison Co., Chicago. The rated plant capacity was 65,748 kw. in the winter of 1905–6 and 364,250 kw. in 1914–15, averaging 210,244 kw.; the peak load was 53,810 kw. in 1905–6 and 306,200 kw. in 1914–15; the ratio averaged 79%, being 66% in 1907–8 and 86% in 1911–12 and 1913–14.

Eastern Pennsylvania Lt., Heat, & Pwr. Co., Pottsville, Pa. From 1910 to 1915 the rated plant capacity was 4,130 kw.; the peak load increased from 3,010 kw. to 4,620 kw., averaging 4.,000 kw.; the ratio was 73% in 1910 and 112% in 1914 and 1915, averaging 97%. Maximum load given for period of about 5 minutes.

Proportions of Steam and Hydro-Electric Equipment to Load. The following data were compiled from reports from officials of the companies, and are for the year 1915.

Great Western Power Co., San Francisco. Rated capacity, steam,

TABLE I. DATA ON OUTPUT AND LOAD FACTOR OF LARGEST GENERATING SYSTEMS IN AMERICA

1916

System	Peak load (kw.)	Date of peak load	Yearly output (kw.-hr.)	Yearly load factor (%)
Commonwealth Edison Company	369,740	Dec. 19	1,341,964,000	43.20
Niagara Falls Power Company	143,360	Nov. 24	1,015,525,680	80.64
Ontario Power Company of Niagara Falls	123,900	Oct. 12	942,221,900	86.80
New York Edison Company & United Electric Light & Power Company	254,824	Dec. 20	856,385,319	38.30
Montana Power Company	149,740	Dec. 19	867,940,326	84.50
Pacific Gas & Electric Company	141,008	Dec. 19	768,304,907	62.20
Hydraulic Power Company	89,275	Dec. 26	717,079,320	91.50
Toronto Power Company	129,000	Dec. 20	660,873,579	58.40
Public Service Electric Co. of N. J.	174,000	Dec. 14	608,018,729	39.82
Detroit Edison Company	130,200	Dec. 19	546,925,300	47.80
Tennessee Power Company	81,650	Dec. 14	483,354,162	67.00
Shawinigan Water & Power Company	108,000	Dec. 14	478,540,000	50.00
Duquesne Light Company	101,000	Dec. 21	463,537,660	52.30
Philadelphia Electric Company	142,260	Dec. 12	444,785,884	35.6
Pennsylvania Water & Power Company	77,000	....	417,837,600	61.8
Utah Power & Light Company	68,894	Dec. 6	412,726,000	67.8
Great Western Power Company	74,100	Dec. 14	408,391,067	62.65
Mississippi River Power Company	82,400	Nov. 27	393,400,000	54.3
Pacific Light & Power Corporation	82,765	Dec. 22	376,308,731	51.76
Puget Sound Traction, Light & Power Co.	77,030	Nov. 28	353,697,263	51.8
Cleveland Electric Illuminating Co.	84,999	Oct. 25	340,670,721	45.8
Electric Company of Missouri / Union Electric Light & Power Co.	88,544	Dec. 11	333,964,652	43.1

TABLE I.— (*Continued*)

Commonwealth Power, Railway & Light Co.	......	....	315,964,337	....
Southern California Edison Company	60,930	Dec. 28	299,950,513	54.04
Buffalo General Electric Company	65,500	Dec. 14	299,306,640	57.00
New England Power Company	64,000	Dec. 12	246,000,000	44.00
Edison Electric Illuminating Co. of Boston	80,539	Dec. 12	238,557,144	33.72
Edison Electric Illuminating Co. of Brooklyn	67,200	Dec. 19	233,452,500	38.1
Wisconsin Edison Company Milwaukee Electric Railway & Light Co.	64,170	Dec. 5	218,421,711	39.00
Portland Railway, Light & Power Co.	47,335	Nov. 29	194,146,555	46.5
Sierra & San Francisco Power Company	......	....	191,620,000	....
Alabama Power Company	40,500	Dec. 11	184,345,360	51.07
Georgia Railway & Power Company	......	....	172,000,000	....
Minneapolis General Electric Company	43,640	Dec. 14	171,672,890	44.9
Great Northern Power Company	38,200	Nov. 21	163,807,560	48.8
Washington Water Power Company	30,440	Dec. 14	162,825,400	60.80
Adirondack Electric Power Corporation	41,575	Dec. 12 & 22	151,128,310	41.40
Rochester Railway & Light Company	40,250	Dec. 16	146,069,428	41.00
Toledo Railways & Light Company	36,428	Dec. 22	134,842,360	42.2
Virginia Railway & Power Company	33,900	Dec. 18	132,275,000	44.54
Southern Sierras Power Company Nevada-California Power Company	22.400	April 28	131,084,265	66.5
Potomac Electric Power Company	38.600	Dec. 18	122,158,818	36.1
Empire District Electric Company	26,900	Mar. 26	119,280,363	49.7
Southwestern Power & Light Company	25,600	Oct. 5	95,740,000	43.0

31,000 kw.; hydro, 50,000 kw., total 80,000 kw. Ratio of steam to hydro, 62%; to steam plus hydro, 38%. It was planned to increase the hydro capacity to 60,000 kw., making the above ratios 52% and 34%, considered more desirable.

Puget Sound Traction, L. & P. Co., Seattle, Wash. Rated capacity, steam; 19,950 kw.; hydro, 57,750 kw. total: 77,700 kw. Ratio of steam to hydro, 35%; to steam plus hydro, 26%. Peak load, 60,500 kw. Ratio of peak to capacity, 70%. Ratio of steam capacity to peak, 33%. Steam plant on overload will carry 40% of peak which was considered satisfactory.

Utah Power & Light Co., Salt Lake City. Rated capacity, steam, 25,400 kw.; hydro, 85,305 kw., total, 110,705 kw. Ratio of steam to hydro, 30%; to steam plus hydro, 23%. Peak load, 45,064 kw. Ration of peak to capacity, 41%. Ratio of steam capacity to peak, 56%. This last was considered high but not unreasonable. Ratio of steam peak to steam capacity, 59%.

Analysis of Kilowatt-Hour Costs of Combination System. The accompanying data on the generating system and energy costs of the Pacific Gas & Electric Company, San Francisco, Cal., abstracted from Electrical World, August 2, 1913, were brought out during a recent rate investigation by the San Francisco Board of Supervisors' committee on lighting and rates:

COST DETAILS, PACIFIC GAS & ELECTRIC COMPANY

		Per kw.-hr.
Cost of generation, on basis of 72,160,908 kw.-hr.:		
Maintenance of generating capital	$45,813.57	$0.0006349
Generating expenses	530,770.98	.0073554
Taxes	110,247.48	.0015278
Fire insurance	62,018.16	.0008594
Casualty insurance	43,714.67	.0006058
Floating debt, interest	2,480.75	.0000344
General administrative expense	94,811.10	.0013153
	$889,956.71	$0.0123330
Cost of distribution, on basis of 66,957,215 kw.-hr.:		
Maintenance of distribution capital	$123,296.29	$0.0018414
Outside work	186,669.26	.0027879
Statements and collections	34,551.94	.0005160
Office	106,976.93	.0015977
New business	67,706.94	.0010112
Sundry expenses	31,867.07	.0004759
Uncollectible accounts	17,601.07	.0002631
	$568,669.50	$0.0084932
Interest:		
Joint capital, $3,539,903.91 at 7%	$247,793.27	$0.0034339
S. F. capital, $6,853,872.68, at 7%	479,771.08	.0071653
		$0.0105992
Depreciation, 25-year annuity, at 7%:		
Joint capital, $2,523,459.52	$39,897.16	$0.0005959
S. F. capital, $4,868,808.43	76,978.30	.0011496
		$0.0017455

SUMMARY OF COST OF ELECTRICITY

Maintenance of capital	$0.0024763
Generation	.0073554
Distribution	.0066518
Overhead expense	.0043426
Interest	.0105992
Depreciation	.0017455
Total	$0.0331708
Deduct revenue from minimum charge, $11,972.63	.0001788
Net cost per kw.-hr.	$0.0329920

The steam plants of the Pacific Gas & Electric Company produce about 78,000,000 kw.-hrs., in addition to which 19,000,000 kw.-hrs. is received from the hydroelectric stations of the system. Of the 97,000,000 kw.-hrs. thus available at the switchboard it is estimated that 31%, or 30,000,000 kw.-hrs., is lost in distribution, in addition to 150,000 kw.-hrs. consumed by the company itself, leaving 66,-957,215 kw.-hrs. as the basis for figuring cost of distribution. To nearby hydroelectric lines the company sells, however, about 5,200,-000 kw.-hrs., making a total generation of 72,160,908 kw.-hrs. (to be exact), which is taken as the basis for calculating unit generating cost.

Operating and Cost Data for Electric Railway Power Stations. Electrical World, October 28, 1916. The data in table II are a summary of similar information compiled for seven electric railway power stations by the power generation committee of the American Electric Railway Engineering Association and presented in its report at the convention held at Atlantic City, N. J., Oct. 9–13, 1916. The information was secured from typical power stations in various parts of the country, some of which employ large modern turbines, others combined low-pressure turbines and reciprocating engines, and still others all reciprocating engines. The range in rating is from 6000 kw. to 65,000 kw. The committee pointed out in presenting these data that to obtain a fair comparison of operating efficiencies and costs which may be generally applied, a much greater amount of information should be obtained in each case, such as daily load curves, labor costs for various classes of work, facilities for receiving and disposing of coal and water, cooling water limitations, etc. The data, however, give in a general way the tendencies in regard to electric railway station performance under varying conditions of load factor, fuel cost and types of equipment.

In commenting upon these data, L. P. Crecilius, Cleveland (Ohio) Railway Company, pointed out that there is less than 5% difference in expense between the operation of the best modern turbine plant, according to data furnished by the committee, and that of an old direct-current engine plant. The reason given was that most of the remaining power stations of this character were built fifteen to eighteen years ago and located without suitable regard for water facilities. It was of prime importance to locate these stations more with regard to accommodating the low-tension distribution systems because of the restriction imposed by the 600-volt equip-

TABLE II. STEAM PLANT OPERATING AND COST DATA FOR DIFFERENT TYPES OF EQUIPMENT

Operating and cost items	Modern turbines				
Plant Number	1	2	3	4	Average
Net output from bus, kw-hr.	130,076,945	111,082,725	91,402,690	172,927,100	126,372,365
Maximum one-hour peak, kw-hr.	42,000	33,240	23,000	46,100	38,085
Capacity for two-hour peak, kw.	45,000	37,000	44,700	65,700	48,100
Plant factor — average kw.-hr. to two-hour rating	0.33	0.34	0.234	0.30	0.30
Load factor, one hour to average kw-hr.	0.35	0.38	0.453	0.428	0.403
Pounds of coal per kw-hr.	1.75	1.97	2.78	2.48	2.245
B.t.u. as received					
B.t.u. per kw-hr.	14,459	14,250	13,000	13,300	13,752
Management and care, total	25,300	28,100	36,200	33,232	30,708
Management and care in per cent.:	$410,810.20	$397,739.49	$261,734.16	....	$356,761.28
Buildings	0.41	0.27	0.14	0.99	0.45
Maintenance	3.91	7.25	7.55	11.30	7.50
Wages	8.81	7.25	15.61	17.60	12.32
Fuel for power	84.58	83.84	72.48	64.30	76.30
Water for steam	0.78	....	0.00	0.62	0.47
Lubricants	0.17	0.61	0.79	1.10	0.67
Miscellaneous supplies	1.34	0.78	3.43	4.07	2.41
Total of above accounts	100.00	100.00	100.00	100.00	100.00
Total cost per kw-hr	$0.00316	$0.00358	$0.00286	0.578*	....
Fuel cost per kw-hr.	.00267	.00300	.00207	.372*	....
Labor cost per kw.-hr.	0.00028	0.00026	0.00045	0.102*	....

TABLE II.—*Continued.*

Operating and cost items	All engines				Low pressure turbines and engines
Plant Number	1	2	3	Average	
Net output from bus, kw-hr.	41,304,359	43,314,700	44,988.468	43,202,509	68,841,300
Maximum one-hour peak, kw-hr.	13,900	8,500	11,050	11,150	13,000
Capacity for two-hour peak, kw	16,875	6,400	11,000	11,425	11,750
Plant factor — average kw.-hr. to two-hour rating	0.28	....	0.467	0.373	....
Load factor, one hour to average kw-hr.	0.339	0.58	0.465	0.461	0.604
Pounds of coal per kw-hr.	2.58	4.19	3.90	3.56	3.21
B.t.u. as received	14,165	13,100	12,530	13,265	13,300
B.t.u. per kw-hr.	36,400	54,889	48,801	46,697	42,693
Management and care, total	$233,089.52	....	$240,679.83	$236,884.67	....
Management and care in per cent.:					
Buildings	0.28	0.57	0.41	0.42	3 044
Maintenance	8.81	8.96	9.59	9.12	17.142
Wages	16.10	20.30	21.57	19.32	24.007
Fuel for power	66.50	55.40	60.77	60.89	49.982
Water for steam	5.60	11.37	3.41	6.79	3.016
Lubricants	1.14	1.54	2.70	1.79	0.906
Miscellaneous supplies	1.57	1.82	1.55	1.67	1.803
Total of above accounts	100.00	100.00	100.00	100.00	100.000
Total cost per kw-hr	$0.00570	2.31*	$0.00535	......	1.45*
Fuel cost per kw-hr.	.00370	1.28*	....	......	0.726*
Labor cost per kw.-hr.	0.00091	0.468*	....	......	0.349*

* Millionths of 1 per cent.

ment. The range of usefulness of this type of plant was limited to a radius of less than 15,000 ft., making it impossible to serve the average railway system from a single plant. The rating of such plants was confined to about 1200 kw. The addition of low-pressure turbines coupled to direct-current generators has in a few cases prolonged somewhat the effective life of such plants, but taken as a whole, the continued expansion and growth of electric railway systems has outdistanced this type of station because of its inflexibility.

Labor Costs of Operation in Street Railway Power Plants. The following costs were taken from tables in Data, November, 1913, and February, 1914, by C. C. Moore & Co.

ALTERNATING CURRENT PLANTS

		No. of men and rate per month			
Size of plant, kw.		2,000	2,500	3,000	4,000
Chief engineer		1–$125	1–$125	1–$125	1–$125
Ass't engineer		......	......	......	......
Watch engineer		2– 100	2– 100	2– 100	2– 100
Boiler room engineer		......	......	......	......
Oilers		3– 60	4– 60	4– 60	4– 65
Fireman		1– 65 2– 70	1– 65 2– 70	3– 70	3– 75
Boiler cleaners		1– 65	1– 70	1– 70 2– 60	1– 70 2– 65
Wipers		2– 60	2– 60	2– 60	2– 60
Generator men		2– 60	2– 70	2– 70	2– 70
Total cost of labor per year		$12,180	$13,200	$14,940	$15,240
Cost of labor per kw. per yr.		$6.09	$5.28	$4.98	$3.81
Cost of labor in dollars per kw-hr. at load factors noted	$0.25(a)	.00278	.00241	.00227	.00174
	.33⅓	.00209	.00181	.00171	.00130
	.50	.00139	.00121	.00114	.00087
	.75	.00093	.00090	.00076	.00058
	1.00	.00070	.00060	.00057	.00043

Size of plant, kw.-hr.	5,000	7,500	10,000	15,000	20,000
Chief engineer	1–$135	1–$135	1–$150	1–$200	1–$250
Ass't engineer	......	......	1– 120	1– 125	2– 125
Watch engineer	3– 100	3– 110	2– 120	5– 110	5– 110
Boiler room engineer	......	1– 90	1– 90	1– 100	1– 100
Oilers	5– 65	8– 65	10– 65	15– 65	20– 65
Firemen	3– 75	5– 75	6– 75	10– 75	12– 75
Boiler cleaners	3– 65 1– 70	6– 65	7– 65	10– 65	2– 70 10– 65
Wipers	3– 60	3– 60	4– 60	6– 60	8– 60
Water tenders	......	......	3– 75	3– 75	6– 75
Electricians	......	......	......	1– 90	1– 90
Switchboard men	1– 75	2– 80	1– 85 2– 80	3– 85	3– 85
Generator men	1– 65 2– 70	3– 65	2– 65	3– 65	5– 65
Clerks	......	1– 70	1– 65 1– 70	1– 65 1– 70	2– 65 1– 70
Total labor cost, year	$20,520	$29,340	$37,560	$55,320	$71,280

Labor cost per kw. per yr.		$4.10	$3.91	$3.76	$3.69	$3.56
Cost of labor in dollars per kw.-hr. at load factors noted	0.25(a)	.00187	.00179	.00172	.00168	.00163
	.33⅓	.00141	.00134	.00129	.00126	.00122
	.50	.00094	.00089	.00086	.00084	.00081
	.75	.00062	.00060	.00057	.00056	.00054
	1.00	.00047	.00045	.00043	.00042	.00041

(a) Yearly plant load factor based on 365 days, 24 hours per day, 8760 hours per year.
All plant under 4000 k.w. capacity are operated continuously for 20 hours per day, two 10-hour shifts.

DIRECT CURRENT PLANTS

Size of plant, kw.		No. of men and rate per month 100	200	250	300
Chief engineer		1–$85	1–$85	1–$85	1–$90
Watch engineers		1– 80	1– 80	1– 80	1– 80
Oilers		.....	.....	.....	.....
Firemen		1– 60	1– 60	1– 60	1– 60
Boiler cleaners		.....	.....	.....	.....
Wipers		.....	.....	.....	.....
Generator men		.....	.....	.....	.....
Total cost of labor per yr.		$2,700	$2,700	$2,700	$2,760
Cost of labor per kw.. per yr.		$27.00	$13.70	$10.80	$9.20
Cost of labor in dollars per kw-hr. at load factors noted	0.25(a)	.01233	.00616	.00493	.00420
	.33⅓	.00925	.00462	.00370	.00315
	.50	.00616	.00308	.00247	.00210
	.75	.00410	.00205	.00164	.00140
	1.00	.00308	.00154	.00123	.00105

Size of plant, kw.		400	500	750	1,000	1,500
Chief engineer		1–$90	1–$90	1–$90	1–$110	1–$120
Watch engineers		1– 80	1– 85	1– 85	1– 90	1– 90
Oilers		.....	1– 60	1– 60	2– 60	2– 60
Firemen		1– 60	1– 60	2– 70	2– 70	2– 70
Boiler cleaners		.....	.....	.....	......	1– 65
Wipers		1– 60	1– 60	1– 60	2– 60	2– 60
Generator men		.....	.....	.....	......	2– 60
Total cost of labor per yr.		$3,480	$4,260	$5,220	$6,960	$9,300
Cost of labor per kw. per yr.		$8.70	$8.52	$6.96	$6.96	$6.20
Cost of labor in dollars per kw-hr. at load factors noted	0.25(a)	.00397	.00389	.00318	.00318	.00283
	.33⅓	.00289	.00292	.00238	.00238	.00212
	.50	.00199	.00195	.00159	.00159	.00142
	.75	.00132	.00130	.00106	.00106	.00094
	1.00	.00099	.00097	.00079	.00079	.00071

(a) — Yearly plant load factor based on 365 days, 24 hours per day = 8,760 hours per year.
NOTE: All the above plants are operated continuously for 20 hours, two 10-hour shifts.

Relation of Unit Labor Costs to Size of Plant for Central Station Work. Howard S. Knowlton published in the Engineering Magazine, Sept., 1909, the following table.

The force at Plant A consisted of 6 engineers, 8 firemen, and 8 engineroom and switchboard attendants in the total 24 hours. The generating equipment included 6 125-h.p., 2 350-h.p., and 4 400-h.p.

TABLE OF LABOR COSTS IN SELECTED CENTRAL STATIONS

Plant	Appx. kw. rating	Total station wages	Kw.-hrs. manuf'd.	Labor cost per kw.-hrs., cts.	Total mfg. cost per kw.-hrs. cts.	Total No. station employees
A	6,000	$25,937	8,776,165	0.296	1.21	22
B	5,000	20,920	6,043,204	0.346	1.23	20
C	4,000	19,429	5,400,192	0.36	1.24	28
D	2,000	9,954	3,288,623	0.302	1.42	11
E	2,000	9,663	4,305,003	0.224	1.27	13
F	1,250	6,844	1,470,066	0.465	1.56	8
G	950	8,771	1,479,898	0.595	2.05	7
H	700	6,669	889,760	0.750	2.34	8
I	630	5,017	730,458	0.685	1.80	6

boilers; 1 1,000-h.p. and 3 900-h.p. engines, horizontal compound condensing type; and 2 1500-kw. vertical steam turbines. A considerable proportion of the 15 generators in the station were belt-driven. The station design when the figures were taken was unfavorable to labor economy.

Plant B was a modern station with economical direct-connected machinery, and had 6 400-h.p. boilers, 1 300-h.p., 1 2250-h.p., and 2 750 h.p. engines, all of the vertical cross-condensing type. The force consisted of 4 engineers, 3 oilers, 1 wiper, 4 switchboard men, 6 firemen and 2 coal passers. Probably this plant was somewhat over-manned.

Plant C was a process of evolution from the belt-connected to the direct-coupled stage, much of the transformation having been accomplished. The equipment consisted of 12 250-h.p. boilers, hand-fired, 1 1500-kw. vertical turbo-alternator, 1 300-h.p., 1 600-h.p., 1 1200-h.p. and 1 1800-h.p. cross-compound condensing engines. The electric generators were 11 in number, 4 being used temporarily for arc service. The force consisted of 4 engineers, 5 firemen, 16 engine-room and electrical operating men, and 3 machinists. The size of the force is undoubtedly due to the design of the station. The plant covered a large floor space and is electrically sub-divided so that not all the switchboard apparatus can be covered from any one point.

Plant D is of almost the same design as Plant B, but of much smaller capacity. Here the labor requirements have been carefully worked out with consequent results. The force consisted of 4 engineers, 3 oilers, 3 firemen, and 1 helper. The plant had 5 boilers of 258 h.p. each, and the following generating units, all direct connected: 1 600-h.p. engine, 1 900-h.p. engine, and 1 1500-h.p. engine, all vertical cross-compound condensing units. The switchboard was a compact hand-operated structure, centrally located on the engine-room floor. The boilers were hand-fired.

Plant E got its principal load from an adjacent street-railway system. The force consisted of 3 engineers, 3 firemen, 2 coal passers and 5 helpers. The boilers were 1 125-h.p., and 9 150-h.p. units, and engine sizes were 2 400-h.p. simple engines, and 1 100-h.p., 1

1250-h.p., and 1 200-h.p., and 1 800-h.p. compound condensing units, with 15 generators.

Plant F had 4 boilers aggregating 1000 h.p. and 3 horizontal cross-compound condensing direct-connected engines rated respectively at 240, 450 and 1000 h.p. The force consisted of 4 engineers

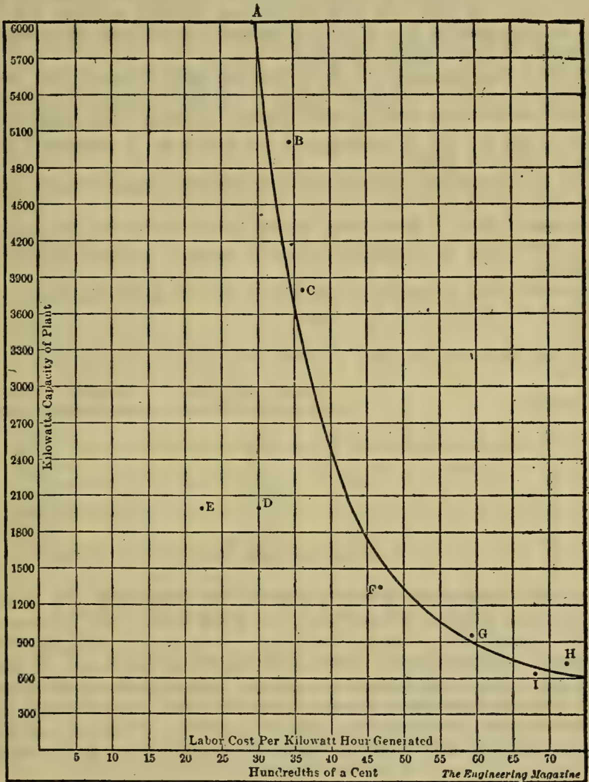


Fig. 3A. Curve of approximate relation between station capacity and cost of wages.

and 4 firemen, and the conditions generally were favorable to the economy of labor, but the plant was handicapped by a small yearly output, being located in suburban town with little opportunity to develop a substantial motor load.

Station G was of combined engine and steam turbine equipment.

well maintained, with moderate sized units of both belted and direct-connected type. 4 boilers of 678 total rated h.p., with 2 horizontal cross-compound condensing engines of 175 and 350 h.p. and a 500-kw. vertical steam-turbo alternator. The operating force consisted of 3 engineers, 2 firemen, and 2 electrical attendants.

Station H included 3 horizontal cross-compound condensing engines, rated at 250 h.p. and a 211-h.p. simple engine, fed by 4 boilers aggregating 600 h.p. in capacity. The force consisted of 3 engineers, 2 oilers and 3 firemen.

Plant I was equipped with 3 engines and 6 generators, with a liberal proportion of belted units, 3 boilers aggregating 550 h.p., and all the engines were of the cross-compound condensing type, 2 being rated at 250 h.p., and one at 125 h.p. 3 engineers and 3 firemen did the work.

Fig. 3a shows the relation between station capacity and the cost of wages.

Plants D and E are doing much better than the average and show what can be accomplished with even a medium capacity installation.

The following table from the above figures gives the plant capacity and labor cost per kw. unit.

TABLE OF PLANT CAPACITY AND LABOR COST

Plant	Approx. kw. per station employee	Station wages per kw. station capacity
A	272	$4.31
B	250	4.18
C	136	5.10
D	182	4.97
E	154	4.83
F	157	5.45
G	136	9.25
H	87.5	9.52
I	105	7.95

Cost of Generating Electric Power for Operating the Elevated and Subway Cars in Manhattan, New York City. The Interborough Rapid Transit Co. operates both the subway and the Manhattan elevated, and generates some 400,000,000 kw.-hrs. of electricity annually. The following data as to the cost of producing this power were deduced from their annual report for 1908 and published in Engineering and Contracting, Apr. 27, 1910. There are 2 power plants, and the following is their total equipment and rated capacity:

Station equipment:

Boilers, 130 units	72,880 hp.
Superheaters, 12 units	9,744 hp.
Economizers, 36 units	261,040 hp.
Steam engines, 17 units	131,500 hp.
Turbo-generators, 4 units	10,250 kw.
Generators (direct A. C.), 17 units	85,000 kw.
Station transformers, 12 units	2,625 kw.
Storage battery cells, 240 units	2,000 amp hr.
Rotaries, 3 units	2,400 kw.
Exciters, 9 units	2,250 kw.

Substation equipment:

Rotary converters, 84 units	126,000 kw.
Transformers, 252 units	138,600 kw.
Miscellaneous, 39 units	2,109 kw.

There were 402,084,635 kw.-hrs. produced, of which all was used to operate the subway and elevated railways except 10,181,000 kw.-hrs. which were sold. The selling price ranged from 1.25 to 3.5 cts. per kw.-hr., depending on the amount consumed.

"Shop Expense," and "Undistributed Expense," are charged to maintenance of rolling stock as well as power plant, so we have roughly prorated these items to the power plant maintenance, although it is by no means certain exactly how they should be charged.

"Buildings and Fixtures," probably includes a considerable sum spent on buildings other than power plant buildings, and this should be borne in mind when considering the following unit costs:

	Cts. per kw-hr.
Maintenance:	
Electric line	0.037
Buildings and fixtures	0.048
Steam plant	0.050
Electric plant	0.013
Shop expense	0.019
Undistributed expense	0.004
Total maintenance	0.171
Operation of power plant:	
Wages	0.105
Fuel, 2,835 lb. at $2.95 per ton	0.353
Water	0.032
Lubricants and waste	0.009
Miscel. supplies and expenses	0.020
Undistributed expense	0.021
Total operation of power plant	0.540
Total maintenance and operation	0.711
General expense (5½%)	0.039
Grand total	0.750

Although the item of "General Expense" amounted to 10.7% of the total operating expenses of the Interborough Rapid Transit Co., nearly half this general expense was due to damages and legal expenses. Eliminating these, the general expense would not amount to more than 5.5%, so we have estimated it on that basis.

The cost of the power plant (55,000 kw.) and transmission line of the subway is reported to have cost as follows:

Electric transmission lines	$ 83
Buildings and fixtures	83
Power plant equipment	112
Real estate	25
Total	$303

This is a high unit cost for the transmission lines and the buildings. Since the 95,000 kw. plant (subway and elevated) produced 402,084,000 kw.-hrs., each kw. produced 4,243 kw.-hrs. during the

year. Since there are 8,760 hrs. in a year, the plant operated under an average load factor of $4{,}243 \div 8{,}760 = 48.5\%$.

Assuming, for illustration, that the first cost of each kw. of plant was $300, and that interest was 6%, we should have $18 interest. This divided by 4,243 kw.-hrs. gives 0.42 cts. per kw.-hr. to be charged to interest on investment, which, added to the 0.75 cts. maintenance and plant operation, gives a grand total of 1.17 cts. per kw.-hr. The maintenance of plant and transmission line cost 0.17 ct. per kw.-hr., which is equivalent to only 2.5% on a plant whose first cost is $300 per kw.

If we consider only the power plant equipment ($112 per kw.), the maintenance was 0.086 ct. per kw.-hr. Since each kw. produced 4,240 kw.-hrs., this is equivalent to $4{,}240 \times 0.086$ ct. = $3.65 per kw. for power plant equipment maintenance. Since this is less than 3.3% of $112, the first cost, it is evident that these maintenance costs are far below what they will be a few years hence, when the plant is older. The elevated railway power plant was put in operation in 1904, and the subway in 1905.

There were 2,385 lbs. of bituminous coal used per kw.-hr., and the price was $2.95 per ton of 2,000 lbs.

The Interborough Rapid Transit Co. had the following number of employes operating both the subway and the elevated during the year ending June 30, 1908:

General office staff:		
467	employes general office staff	$657,024
Transportation:		
106	Train clerks and dispatchers.	
21	Starters.	
11	Depot masters.	
686	Ticket agents.	
740	Gatemen and platform men.	
2,173	Guards.	
530	Conductors.	
595	Motormen.	
358	Switchmen, flagmen and yardmen.	
1,198	Road and track men.	
302	Station porters and watchmen.	
2	Other employes.	
6,722	Total transportation	$4,517,304
Power:		
32	Engineers.	
104	Oilers.	
19	Wipers.	
122	Firemen (stoker operators).	
22	Coal passers.	
30	Water tenders.	
23	Ashmen.	
32	Boiler cleaners.	
89	Dynamo and switchboard men.	
30	Electricians.	
23	Linemen.	
246	Other power plant employes.	
722	Total power	578,493

Car houses and shops:

189	Car cleaners.
22	Lamp trimmers.
169	Car house men.
48	Other car house employes.
210	Carpenters.
38	Blacksmiths.
94	Machinists.
114	Machinists' helpers.
3	Brass moulders.
208	Electrical helpers.
155	Painters.
310	Other shop employes.
1,560	Total car house and shops. . . . . $ 857,900
9,521	Grand total 6,610,722

This is equivalent to an average wage of $13.40 per employe per week.

	Car miles
Rapid Transit Subway	44,005,213
Manhattan Ry. Co. (Elevated)	64,584,609
Total, Interborough Rapid Tr. Co.	108,589,822

Since 391,900,000 kw.-hrs. were generated for 108,589,822 car miles, it required 3.6 kw.-hrs. per car mile, at an average speed of 16.08 miles per hr. (including stops). There were 4.45 passengers per car mile, or 71.57 passengers per car hour.

Cost of Generating and Distributing Electricity for Lighting and Power. The following data are based upon the report of the New York Edison Co., for the fiscal years ending June 30, 1907, as published in Engineering and Contracting, May 11, 1910.

Plant.— There are 8 generating stations having a total rated capacity of 108,300 kws., but 2 of these stations supply nearly 80% of the current. There are 23 substations of 93,750 kws. capacity. The details of the plant equipment are as follows:

Station equipment:

144 boilers, water tube	76,382 hp.
45 superheaters	29,250 hp.
30 steam engines, direct connected.	82,900 hp.
5 steam engines, belted	1,725 hp.
9 turbo-units, a.c.	53,500 kw.
21 generators, direct connected, a.c.	93,000 kw.
34 generators, direct connected, d.c.	14,100 kw.
3 generators, belt connected, a.c.	900 kw.
2 generators, belt connected, d.c.	300 kw.
10 exciters, motor driven	1,400 kw.
3 exciters, steam driven	225 kw.
2 x 140 storage battery cells.	12,000 ah.
2 station transformers	2,500 kw.
1 frequency changer	1,000 kw.

Substation equipment:

100 rotary converters, etc.	93,750 kw.
276 transformers for rotaries	108,735 kw.
32 by 150 storage battery cells, 3 hr. rate.	192,000 ah.

The company had 70,533 meters and 34,531 arc lamps in service, of which lamps it owned about half, and 2,655,085 incandescent

lamps. In round numbers there were the following amounts of circuits:

	Ft. of circuit	Million mil. ft. of wire
Direct current (underground)	10,183,000	4,619,000
Alternating current (underground)	1,000,000	179,000
Alternating current (overhead)	1,096,000	794,000
Total	12,279,000	5,592,000

There were 639,735 lin. ft. of streets occupied by pole lines. The underground wires occupied conduits rented from other companies, a rental of $1,000 per mile of single 3-in. duct per year being paid; aggregating a total of $845,000. This is an enormous rental, but it should be remembered that the Edison Co. controls the companies from which it rents the conduits.

The company owned 74,169 meters, the first cost of which is not reported. The Edison Illuminating Co. of Brooklyn owned 18,088 meters whose first cost averaged $18.40 each.

The company owned the following lamps:

1,957 arc — a.c. inclosed.
13,806 arc — d.c., inclosed.
1,813 Nernst.
6,522 Glowers.

The total number of arc lamps on its circuits Dec. 31, 1907, was 34,547, and the total number of incandescents was 3,056,777.

There were 299,172,431 kw.-hrs. produced (at the switchboard) and 209,024,002 kw.-hrs. sold (at the meters), showing a distribution loss of 30%.

Since the plant capacity was 108,300 kws. and since there are 8,760 hrs. in a year, the total capacity was 950,708,000 kw.-hrs. Therefore the plant factor was 299,172,431 ÷ 950,708,000 = 31.5%. Each kw. produced 2.760 kw.-hrs. at the switchboard during the year, of which 70%, or 1,932 kw.-hrs., was sold.

The operating expenses per kw.-hr. produced (at the switchboard) were as follows:

	Cents per kw-hr.
Production expense:	
Salaries	0.012
Labor	0.171
Fuel	0.406
Oil, waste and sundries	0.018
Water	0.045
Repairs, buildings and structures..........	0.012
Repairs, motive power	0.070
Repairs, electric apparatus	0.007
Station expense	0.008
Purchased power	0.025
Total production expense	0.774
Distribution expense:	
Salaries	0.021
Substation labor and expense	0.050
Rental of conduits, etc.	0.339

	Cents per kw-hr.
Incandescent lamp renewals	0.147
Wiring and jobbing	0.047
Repairing and maintaining str. lamps	0.023
Repairs, substation buildings and apparatus	0.068
Repairs, poles and lines	0.007
Repairs, subways and cables	0.019
Repairs, meters	0.074
Repairs and expense commercial lamps	0.004
Total distribution expense	0.799
General expense:	
Salaries of officers	0.017
Office salaries	0.113
Office expenses	0.098
Legal expenses	0.039
Advertising and soliciting	0.073
Insurance	0.040
Engineering and testing	0.026
Leaseholds, rentals, etc.	0.016
Total general expense	0.422
Taxes	0.235
Uncollectible bills	0.011
Depreciation and contingent expense	0.575
Grand total	2.816

The cost of operation was as follows per kw.-hr. produced (at the switchboard) and per kw.-hr. sold:

	Cents per kw-hr. Produced	Sold
Production expense	0.78	1.11
Distribution expense	0.80	1.14
General expense	0.42	0.61
Taxes	0.24	0.34
Uncollectible bills	0.01	0.02
Depreciation, contingency and renewal	0.57	0.82
Total	2.82	4.04

In considering these costs, it should be remembered that 35% of the "Distribution Expense" is due to the rental paid for conduits at an exceedingly high rate.

The item of "Depreciation and Contingencies" is worthy of special note, as it aggregates the large sum of $1,721,413. Of this sum $594,735 was actually charged off for depreciation, the balance going to a "contingency and renewal fund," which, so far as can be ascertained from the report, is but another name for a depreciation fund.

The report does not show what the plant actually cost, but it does show that $43,417,883 bonds have been issued, which doubtless represents approximately the actual cost, or about $400 per kw. capacity. Possibly additions, paid for out of earnings, have increased the cost to $500 per kw.

As throwing light on what such a plant may actually cost in New York City, the following data relative to the United Electric

Total efficiency 56

Light and Power Co. will serve. This company was incorporated in 1887, and on June 30, 1907, it was operating 4 generating stations of a combined capacity of 10,200 kws. Its cost of construction and equipment was as follows:

	Per kw.
Land for generating stations	$ 22
Land for substations	3
Buildings for generating stations	23
Buildings for substations	5
Electrical and steam apparatus (generating)	92
Substation apparatus	31
Construction cables	165
Subsidiaries	20
Tools and implements	2
Stable equipment	4
Office furniture and fixtures	1
Installation: Includes line transformers, meters, arc lamps, motors, etc.	142
Maps and instruments	3
Total	$523

The United Electric Light and Power Co. rented its conduits of which it occupied about 300 miles of ducts, and it had 820,000 million mil. ft. of wire.

In our issue of April 6 we showed that the first cost of the plant of the Edison Electric Illuminating Co. of Brooklyn was $437 per kw.

Let us express the cost of repairs on the New York Edison plant in terms of kws. of rated capacity:

Repairs:	Per kw.
Station buildings and structures	$0.35
Motive power	1.95
Electric generating apparatus	0.21
Substation buildings and apparatus	1.87
Poles and lines	0.20
Subways and cables	0.52
Meters	2.54
Street arc lamps	0.63
Commercial arc lamps	0.12
Total	$8.37
Incandescent lamp renewals	4.46
Grand total	$12.83

If these repair costs are expressed in percentages of the probable first costs of the various items, it will be seen that they are all very low. It would seem, therefore, that the apparently large amount ($1,721,413) charged off for depreciation and renewals is none too high.

We have seen that the actual cost, as reported, was 4.04 cts. per kw.-hr. sold. The average income was 6.49 cts. per kw.-hr. sold. The plant represents a first cost of $500 per kw.— the interest charge at 6% would be $30 per kw. We have seen that each kw. produced 1,932 kw.-hrs. sold. Hence $\$30 \div 1{,}932 = 1.56$ cts. This is the interest charge, which added to 4.04 gives a total cost of 5.60

cts. per kw.-hr. sold. This would leave a profit of nearly 0.9 ct. per kw.-hr. It should be remembered, however, that we have assumed a high first cost, and that a high price was paid for rental of conduits. However, no exorbitant profit has been made although the profit has unquestionably been liberal.

The payroll was approximately as follows for the year ending June 30, 1907, based upon the payroll for the week ending June 29, 1907:

Employes:		Total
881	General	$ 672,678
519	Technical	447,283
857	Generating plants	756,050
122	Substation plants	110,113
972	Distribution department	727,677
565	Construction department	450,694
98	Monthly salaries	256,306
4,014	Total	$3,420,801

This is equivalent to an average of nearly $16.40 per man per week. That this payroll is higher than normal is quite evident from the following tabulation of wage earners on the payroll June 30 and Dec. 31, 1907. The average wage is that paid by the Edison Illuminating Co. of Brooklyn, which presumably differed little from the New York Edison Co.

	June 30	Dec. 31
Foremen at $3.80	103	103
Assistant foremen at $4.03	43	44
Inspectors at $3.09	40	48
Engineers at $3.95	52	51
Firemen at $2.85	130	148
Coal passers at $2.22	31	47
Oilers and water tenders at $2.49	201	202
Electricians at $2.67	109	39
Electricians helpers at $1.84	...	24
Dynamo attendants at $2.33	47	40
Switchboard attendants at $3.13	97	100
Machinists at $2.77	56	48
Machinists helpers at $2.13	56	53
Blacksmiths at $2.43	9	8
Linemen at $2.44	14	13
Lamp trimmers at $1.66	37	30
Wiremen and helpers at $2.59	186	131
Meter readers at $2.96	36	37
Teamsters and stablemen at $2.40	96	72
Electric wage earners not elsewhere specified at $1.76	1,172	782
Total wage earners	2,515	2,020

The number of salaried employes and their weekly wages for the same time were as follows:

Canvassers at $25.48	71	55
Cashiers and bookkeepers, men, at $20.69	93	98
Cashiers and bookkeepers, women	25	26
Clerks (men) and salesmen at $15.93	395	343
Clerks and saleswomen at $8.71	36	40
Collectors at $23.36	29	34
Demonstrators at $14.46	1	..

	June 30	Dec. 31
Messengers, telephone operators, etc., at $6.87..	55	47
Stenographers, men, at $10 58..................	39	36
Stenographers, women, at $13.01	65	57
Superintendents	17	17
Watchmen, elevator men. etc.	132	110
All other salaried employes	533	429
Total salaried employes	1,491	1,282
Grand total employes	4,006	3,302

The average weekly salaries are based on those paid by the Edison Illuminating Co. of Brooklyn.

For the half year, July 1 to Dec. 31, 1907, the total payroll was:

Officers (5)	$ 25,000
Salaried employes	626,955
Wage earners	988,320
Total	$1,640,275

During this same half year, 166,731,594 kw.-hrs. were generated, and it required 4.11 lbs. of coal per kw.-hr. generated. The coal was nearly all anthracite, less than 20% being bituminous, and the average price was $1.96 per ton of 2,000 lbs. The high coal consumption and the low price indicate a very poor quality.

Cost of Producing Electric Power. Engineering and Contracting, July 31, 1907, gives the cost of producing electric power at the station of the Cincinnati, Milford & Loveland Tracton Co., operating 36 miles of interurban electric railway. The plant is briefly described as follows: The boilers are 4 400-h p. Sterling, operating under natural draft 8 (small) furnished by 2 54-in. by 100 ft. steel stacks, 4 6 by 4 by 6 in. Dean pumps in duplicate handle the feed water, 1 pump running water to an 800-h.p. Cochrane open type heater where the temperature is raised to 210 deg. F. and the other pump running the water from the heater to the boilers. Condensing water is supplied to a 750-h.p. Tomlinson condenser by 2 single stage centrifugal pumps direct operated by 7 by 7-in. marine engines. These pumps operate at 300 rev. per min. and deliver 1,200 gals. per min. The circulating pumps are set in a 12-ft. pit in the boiler room and have a minimum life of 50 ft. The engines are 16 by 34 by 42-in. Allis-Chalmers cross-compound condensing. In order to give a high output for their size the engines are operated at 125 rev. per min. The generators are 500-kw. Bullock revolving field machines. They generate 3 phase 25 cycle current at 400 volts pressure and have an output of 721 amperes. Current for distribution of fields and for station lighting is furnished by 22.5-kw. 125 volt generators belted to an extra wheel bolted to the spokes of the flywheel. The following is the statement of the output and operating cost of this station for one month:

Labor:	
2 engineers	$150
2 oilers	100
2 firemen	100
1 general help	45
Total	$395

Fuel and supplies:

342 tons coal at $2.10	$718.20
Oil and waste	37.10
General supplies	33.25
Total	$788.55

The output in kw.-hrs. was 168,000, so that the cost per kw.-hr. at the switchboard was as follows:

Item	Total	Per kw.-hr.
Labor	$ 395.00	$0.00235
Fuel and supplies	788.55	0.0047
Total	$1,183.50	$0.00705

The total amount of coal burned during the month was 684,000 lbs., or 4.07 lbs. per kw.-hr.

Cost of Power. The following is abstracted from a paper by Frederick Darlington presented before the A. I. E. E., Pittsfield, Mass., Jan. 18, 1912.

The figures given below are for the cost of producing electric power in steam plants carrying railroad loads under conditions that are widely prevailing in the United States. These figures are not exact costs taken from any particular power plant, but are average costs worked out from actual results in several steam plants on heavy railroad and other work, so shown as to permit easy analysis for varying conditions of load and for different fuel costs, etc.

	Total cost per yr.	Cost per yr. per kw. of plant capacity	Per kw-hr.
Operating labor	$52,500	$2.10	0.100
Operating materials (exclusive of fuel)	15,000	0.60	0.025
Labor for maintenance of plant	15,000	0.60	0.025
Material per maintenance of plant	17,500	0.70	0.030
Total cost of power plant, operation and maintenance, exclusive of coal per year	$100,000	$4.00	0.180
Add the cost of coal at $1 per ton for coal of 13,500 B.t.u. per lb.	82,500	3.30	0.15
NOTE:— The fuel cost will increase as the cost per ton increases or the quality falls off			
Other expenses pertaining to power plant operation, such as administration, legal and general expenses	10,500	0.42	0.02
	193,000	7.72	0.35
Add for fixed charges on the cost of power plant	225.00	9.00	0.41
Total cost of power per yr. with coal at $1 per ton and a load factor 25%	$418,000	$16.72	0.76

The figures given are the cost, including fixed charges, of producing power in a 25,000-kw. steam turbine plant, containing

5 main units of 5000-kw. nominal capacity each, but capable of carrying 50% overload or more in emergencies.

The yearly production of power is assumed at 55,000,000 kw.-hrs. or a load factor of 25% on a maximum load of 25,000 kws. which is the total nominal capacity of the 5 generators. It is equivalent to an average operation of all of the generators for 2200 hours per yr. at their rated capacity.

Such is the cost of electric power generation by steam for heavy railroad operation and general central station service.

There are 2 factors in the foregoing costs which are liable to maximum variations, viz., the cost of fuel and the average load on the plant, or as it is called, the load factor. The assumed maximum load of 25,000 kws. could easily be carried on 4 ordinary 5000-kw. nominal capacity steam turbine generators, and leave one spare unit in a 5-unit station. At 25% load factor as assumed above (25,000 kws. maximum load and 55,000,000 kw-hrs. per year), the result in thermal efficiency would be about 8.4%. It is difficult to determine from actual results just what the thermal efficiency would be at other load factors, but as it is sometimes necessary to know this as a basis for arriving at the fuel costs under varying load conditions, the following approximate figures are given for these variations. The coal is assumed to contain 13,500 B.t.u. per lb.

Yearly load factor (ratio of maximum load to average output)	Average operation per yr., hrs.	Thermal efficiency of plant	Cost of coal per kw-hr. at $1.00 per short ton
10%	876	6.5%	0.20 cent
20 "	1752	7.8 "	0.16 "
25 "	2190	8.4 "	0.15 "
30 "	2628	9 "	0.14 "
40 "	3500	9.8 "	0.13 "
45 "	3940	10.1 "	0.125 "

It would be difficult to demonstrate in detail the economies that can be derived from combinations of mixed power service from the above plant compared with power for only one industry like railroads, but analysis of the schedules of costs and thermal efficiencies for a 25,000-kw. plant, working at 25 per cent. load factor, proves the broad assertion that in power generation large stations carrying mixed loads afford the maximum economies. Take for example, the cost of general expenses and of fixed charges and of power station labor and material, exclusive of coal. These things are little affected by the load factor, but even in so large a station as 25,000 kws. they amount to $13.42 per kilowatt per year, out of a total cost of power of $16.72 per kilowatt per year, with good coal at $1.00 per ton, or $20.02 with coal at $2.00 per ton, etc. Furthermore, even the fuel cost per unit of power generated will ordinarily be less in mixed service plants than on plants for railroad work only, since the former generally work at better load factors than the latter. The better load factor comes for serving a diversity of operations. Also with more operations the plant will be larger

and for this reason as well it naturally has a better load factor and all unit costs are correspondingly less.

There are other important advantages from centralization of power in large power plants, which will have important bearing on the future of central station business, for industrial and for railroad power. One of these has to do with obsolescence and its importance in this connection does not always receive the attention that it deserves. Another is the utilization of off-peak or secondary power, which so far has been very little realized but which will increase in importance.

Cost of Power in a Plant with a Relatively Large Railway Load. Electric Railway Journal, October 9, 1909. The return of the Hyde Park (Mass.) Electric Light Company to the Board of Gas and Electric Light Commissioners for the year ending June 30, 1909, illustrates the cost of generating electrical energy in a station of moderate size having a large railway load. Although the Hyde Park Company handles an electric lighting and power business in the suburb of Boston where its plant is established, by far the greater portion of its output is utilized in the operation of trolley lines at the south of Boston. The total normal capacity of the station is 1965 kws. and in the year covered by the return the company generated and delivered at its switchboard 3,990,634 kw.-hrs. Its total sales were 3,661,372 kw.-hrs., and of this amount of energy 3,314,076 kw.-hrs. were sold to electric railway lines at a price of practically 2 cts. per kw.-hr., the exact figure being 1.98 cts., as deduced from the return. Practically 92% of the total generated energy was thus sold — a much higher proportion than is usually encountered in central station work, and due without question in this case to the purchase of the railway power at the direct-current switchboard of the station, with the avoidance by the central station of the usual 15 to 30% distribution losses.

The equipment of the Hyde Park plant, as reported in the return, consists of 9 150-h.p. Cunningham boilers with Hartford setting, each having a 72-in. shell and 92 3.25-in. tubes; also 1 125-h.p. Dobbins boiler with a Jarvis setting, 72-in. shell and 140 3-in. tubes built for 110-lb. steam pressure. The total rating of the boiler plant is 1475-h.p. The engine equipment consists of the following units:

1 Corliss compound, 24 by 48 by 48 ins., 80 rev. per min., 1250 hp.
1 Green compound, 24 by 38 by 48 ins., 100 rev. per min., 800 hp.
1 McIntosh-Seymour compound, 13 by 23 by 17 ins., 200 rev. per min., 200 hp.
Direct connected, respectively to 850, 525 and 100-kw., General Electric, 500-volt, d.c., generators.
2 Armington & Sims 18½ by 18 ins., 200 rev. per min., 200 hp. belted and one Armington & Sims compound 10½ by 16½ by 12 ins., 285 rev. per min., 100 hp., belted, driving 6-arc light dynamos, four alternators of a total capacity of 330 kw. and two 500-volt, d.c. generators of 100 kw. rating each.

The station was operated by a total force of 3 engineers, 3 firemen and 2 coal-passers. The company burned a mixture of soft coal costing about $4.21 per ton and buckwheat at $3.26, the total

fuel cost for the year being stated as $34,471.24. The station wages cost for the year was $9,621.86. These were the two principal items of cost at the switchboard, the total expense of manufacture being about $50,000. The principal repairs tabulated were those of the steam equipment, which came to $2,741.45. The electrical repairs at the station were barely $1,100. The power production cost was as follows in detail:

Cost of manufacture at switchboard as follows:

Kw.-hr. delivered at switchboard	3,990,634
Cost of manufacture at switchboard as follows:	
Fuel	$34,471.24
Oil and waste	778.22
Water	273.06
Wages at station	9,621.86
Repairs, station building	90.59
Repairs, steam equipment	2,741.45
Repairs, electrical equipment	1,101.33
Tools and appliances	698.05
Total	$49,775.80

The cost per kw-hr. manufactured in cents was:

Fuel	0.86
Labor	0.24
Miscellaneous	0.15
Total	1.25

Installation and Maintenance of a Small Electric Light Plant. The following is abstracted from an article in the May, 1906, issue of Power. In Jordan, Minn., a town of 1200 inhabitants, was organized the Jordan Electric Light and Heating Company.

Adjoining a side track, and near the central portion of the town a substantial building of brick, with cement tile floors, brick partitions and a gravel roof was erected. It is 20 ft. in width and 54 in length inside.

The source of water supply is a 3-in. tubular well bored just far enough outside the building to allow the working of a well-drilling machine. At a depth of 62 ft. a plentiful supply of water was secured, coming to within 16 ft. of the surface. The well is located opposite the pump section of the boiler-room, the pit extending inside of the building and being open through the floor on the inside, the outside being arched over with brick and covered with dirt, making it frost-proof. An arch in the foundation of the building carries the wall over the pit. Suction is depended on entirely for drawing water. The top of the well casing is fitted with a tee, the run being extended to form a vacuum chamber and the branch leading inside to the pumps. A check is inserted near the well to facilitate priming.

The pumping outfit consists of a Fairbanks, Morse & Company's brass-fitted duplex steam pump 3 by 2 by 4, and a duplex power pump 2.5 by 6, each set on a cement foundation. The stroke of the plungers of the power pump is adjustable from 4 to 6 ins. The pumps are cross-connected so that either can draw from the well or tank and deliver to the boiler, tank or hose. In practice one

cylinder of the power pump draws from the well and delivers to the tank, and the other cylinder draws hot water from the tank and feeds the boiler, the stroke of the plunger being set so that it loses a little during the peak load, and gains on the light loads. A tight-and-loose pulley allows the pump to be stopped when desired, or the water can be by-passed. During the two years of operation of the plant the steam pump has been required but a few hours.

An iron tank which is 6 ft. in diam. and 8 ft. high, with a 5-in. hole in the cover, is placed on the roof, and used as a combined tank and heater. It holds enough water to fill the boiler one and a half times. The 5-in. exhaust pipe is led into it, besides the water inlet and outlet pipes. The heating of the feed-water is accomplished by allowing it to drip over a series of shelves. These become coated with a considerable thickness of scale in a short time which is knocked off and shoveled out through a manhole in the side of the tank. Under running conditions about 3 ft. of water is carried in the tank. The delivery to the pump is taken from a point 8 in. from the bottom through a frost-proof connection. The temperature of the feed-water ranges from 160 to 190 deg. F.

On all feed-piping which is of 1.5-in. extra heavy pipe, tees and crosses are used instead of ells, so that the inside of the pipe can be inspected and cleaned without taking it all down, but this operation has as yet not been necessary. Both cylinders of the power pump are provided with relief valves to guard against breakage in the event of the belt being thrown on when the outlet valves are closed. The feed is carried through the front head of the boiler and discharged about two-thirds of the way back.

The boiler, which is 54 ins. in diam. and 14 ft. long, is of the standard high-pressure, double-butt-strap triple-riveted, horizontal, tubular type, with 44 3.5-in. tubes, and set in a regular air-space brick setting, with stationary grates 4.5 by 5 ft., affording ample grate area for burning low-grade fuel. This grate area has since been reduced to 18 sq. ft. by placing a 12-in. dead-plate across the back ends of the grates, which has improved the firing and economy somewhat, besides affording a good place for banking fires. The 2.5-in. blow-off is protected by brickwork and provided with a Jenkins special blow-off valve. The 4.5-in. main pipe leads from the top of the boiler to a tee, into which is screwed a 3-in. pop safety-valve set at 125 lbs., thence to an angle valve, thence to a tee with a plugged opening to receive steam from a future boiler, and thence to a tee in the engine room, where a 4-in. pipe leads to the engine, a plugged opening being left for future connections. A 2.5-in. auxiliary pipe, also provided with a valve and a plugged opening for future connections, supplies the tube-blower, pump, engine-room gage and city fire whistle. The water column is connected up with extra heavy tees and crosses and provided with blow-offs leading to the ash pit. All live steam piping is covered with .5 in. of felt over .625 in. of asbestos.

The stack, which is supported by the boiler setting in the usual manner, is 30 ins. in diam. and 60 ft. high from the grates. Where

it passes through the roof the woodwork is amply protected by an iron ventilator, having 8 sq. ft. of opening, which can be opened and closed at pleasure. A water-table above the roof effectively prevents water from flowing down the stack into the boiler room. The plates of the stack are inverted with the seams opening upward. After the stack was erected these seams were filled with a good machinery filler and then painted with graphite mixed with linseed oil, which gives the stack a lasting dull black color. No water enters the stack or boiler room, even during the heaviest rains.

The coal room, located between the boiler room and the track, is 11 by 36 ft. inside, and holds about 120 tons of coal. The coal room has two doors for wheeling in coal, also an unloading device which consists of a hay carrier and track, attached to the trussed framework of the roof, and two automatic dumping boxes, discharging through a hatch in the roof. At present this rig is operated with a team of horses, and it requires about 3.5 hrs. to unload a 30-ton car, costing about 8.5 cts. per ton, compared with 10 cts. a ton for unloading with wheelbarrows when the bin is empty and 20 cts. when partly full. The rig has now unloaded upwards of 500 tons and shows no perceptible wear except the rope, which will soon have to be replaced.

The engine room is 15 by 26 ft. inside and contains a Russell 11.5 by 12 single-valve automatic engine running at 300 rev. per min. direct connected to a Westinghouse 45 kw. generator, together with switchboard, desk, show-case, bench, supplies and merchandise stores. The engine is nominally rated at 80 h.p. and is provided with the usual sight-feed oiling devices for continuous running, and a complete set of oil shields, allowing the oil to be fed liberally without waste, insuring against stoppages from insufficient oiling. The oil is then filtered and used over again, about 36 gals. of fresh oil a year being required.

An independent sight-feed was attached to the oil chamber of the lubricator, delivering oil through two .125-in. pipes tapped into the top of the steam-chest casting and connected by .0625-in. holes drilled into the face of the valve seat. Since installing this device, less oil is used with better results. An extension of the engine shaft carries a 10-in. pulley for driving the countershaft which drives the pump in the boiler room adjoining. A 5-in. exhaust pipe is laid under the floor to the boiler room where there is a .5-in. drip leading to a drain for keeping the pipe clear of water. It then extends up through the roof to the tank.

The generator is a Westinghouse three-wire engine-type machine delivering direct current at 115 and 230 volts. The leads and balancing wires are carried through a glazed tile conduit, laid under the floor of the switchboard. On the switchboard are mounted one voltmeter, two ammeters, a field rheostat, and generator, arc and commercial switches. The station lights are wired on a single two-wire circuit and a double-throw switch on the back of the board enables the operator to throw them on either side of the neutral, thus assisting to balance up any unevenness

in the load that may occur from time to time. The usual fuses and lightning arresters are provided.

The distribution is mainly from a complete loop two blocks long and 1.5 blocks wide, the power house being in the center of one side of the loop. This loop is composed of 5 wires, one neutral common to both arc and incandescent lighting, a pair of 00 commercial feeders and a pair of No. 4 arc feeders. Branches are run from this loop to out-lying districts, extending as far as 6 blocks; 100- and 105-volt lamps are used on the longer extensions. This system has given entire satisfaction.

There are now connected 18 arc lamps for the city, run on a moonlight, 1 o'clock schedule, at \$60.00 each per year, and about 700 incandescent lamps, three arcs and three motors aggregating 2.5 h.p., on the commercial lines. About 75% of the service is on meters; the base rate of 12.5 cts. per kw.hr. is discounted, in proportion to the amount used, to 10 cts.

The plant is operated from the usual dusk starting time to 1 A. M. and for 4.5 months of the winter season from 6 A. M. to daylight.

The plant has now been in operation 2 years, but records of operation were not commenced till 5 months after starting, at which time the plant was considered to be in normal condition, and the load was sufficient to make a showing. The total cost of the plant and incidentals as inventoried at that time was, in round numbers, \$7300. During the year ending Nov. 1, 1904, 361.5 tons of central Illinois coal were consumed, costing \$1070.24. The total output for the year was, as nearly as can be estimated from the volt and ammeter readings, 50,370 kw.-hrs., which gives approximately 14.5 lbs. of load per kw.-hr., or \$0.02175 for fuel. It requires about 180 lbs. of coal an hr. to run one lamp; this rate of fuel consumption remains about constant until about 175 to 200 lamps are reached, then it increases with the increase of load to about 250 lbs. for a 34-kw. load.

The load is very regular, gradually coming to a peak which holds on for about two hrs., then gradually falls off to 10 or 15 amperes at shutting down time.

The mason work of the building was let on a contract which covered brick and stone for both building and foundation, lime, cement, sand, excavating and all labor connected with the mason work

for	\$847.50
(Brick was selling in home market at \$5.50 per M.)	
Lumber bill, purchased as needed	184.07
Hardware bill, purchased on bids	30.73
Roof, purchased on bids	43.75
Additional hardware	4.00
Cement tile floors, laid complete	64.10
Carpenter work	15.98
Anchors, bolts and rods	3.75
2 screen doors, 2 windows, and transom	5.50
Paint and painting	16.40
Supt. time charged to building	90.00
	\$1,305.78

The well was drilled for $1.00 per foot including 3-in. casing to the rock, and the pit, costing complete	$ 62.00
The foundation for the boiler and engine were laid at the same time, by the day, the company furnishing the material, therefore it is not practicable to itemize the cost of each, but it is safe to charge 70% to the engine foundation.	
4½ Cd. stone, 1000 brick	$ 25.65
Cement	18.00
Sand	2.10
Labor	22.75
	$ 68.50
For the boiler setting 12 M. brick were used	$ 66.00
600 fire brick, delivered	23.00
Bbl. fire clay	2.50
Lime 14 bbl.	10.50
Cement	3.25
Sand	2.70
Labor	31.30
Superintendence	20.00
	$159.25
Cost of boiler with water-column, safety valve, blowoff, front and castings, and stack	713.00
Tank 6 ft. diam. by 8 ft. high, No. 12 steel	66.00
6 sets of shelves fitted to same	23.00
	$89.00
Freight on boiler and tank	20.70
Cost of engine with sub-base complete, freight allowance to St. Paul	915.00
Erecting and setting on foundation	24.12
Superintendence	12.00
	$951.12
Freight on engine	22.90
Cost of dynamo delivered	1031.05
Setting up and starting	12.00
Switchboard complete	96.00
Station lightning arresters	23.00
Misc. items	18.35
Superintendence	45.00
	$1225.40
The main steam and exhaust pipes were cut to diagrams, and cost, including 4-in. valve on the boiler and all fittings	68.84
Labor of erecting	26.00
	$94.84
The auxiliary piping and valves, fittings, 50 ft. hose, flue blower and scraper, iron wheel-barrow, waste, enough packing to start with, in all making a list about 2 ft. long, cost on bids	176.50
Additional	8.30
	$184.80
Lump price on the power pump, 15 ft. of shafting, self-oiling hangers, and pulley was	56.65
Steam pump	35.35
Freights	2.60
Foundations about	6.40

Labor and superintendence on setting up pumps and fittings, piping in running order	67.50
	$168.50
The line, poles and arc lamps were purchased second-hand and erected at a cost of	950.00
The estimate on new equipment was $1450.00.	
In addition to the above the legal expenses on incorporating	91.50
Labor not charged to any item in particular	97.00
Superintendence not charged to anything in particular	149.64
Wiring power house	13.50
Coal hoist	61.50
Show case (without stock)	9.50
Value of lot occupied	450.00
Pipe covering, put on one year after starting	19.50
Radiators	15.62
Office equipment, small additions, tools, service wires, extensions, the wiring equipment in an amusement hall and park, etc.; a long list of small items growing daily	475.00
Total	$7270.55

OPERATING EXPENSES FOR THE YEAR ENDING NOV. 1ST, 1904

10 gals. cylinder oil	$ 6.00
Insurance	18.78
Floor brush and broom	1.80
Stationery	1.70
10 gals. cylinder oil	7.50
Packing	12.75
10 gals. cylinder oil	6.65
Extra labor	1.60
Repairs	.40
Extra labor	1.60
Stamps and freight	1.25
Taxes	51.00
Expense account	1.53
31 gals. cylinder oil	19.35
Expense account	5.62
Arc globes	1.90
Stationery	2.25
Repairs, power pump	3.25
Repairs	.60
Expense account	.55
53½ gals. cylinder oil	32.10
53 gals. engine oil	13.25
Freight and dray	2.50
Stationery	.60
Repairs	.65
Expense account	5.26
Telephone rent for the year	14.05
Arc globes	1.44
Cross arms and insulators for repairs	4.68
Boiler compound	5.30
Carbons used, about	12.00
	$ 227.91
361½ tons coal	$1070.24
Superintendent's salary, covering all labor expenses connected with operating plant	1100.00
Secretary's salary	25.00
Total without interest or depreciation	$2423.15
Add 10% for interest and depreciation, part of the depreciation was kept up in the shape of repairs	730.00
Grand total of operating expenses for one year	$3153.15

Design and Operation of Cleveland Municipal Electric Light Plant. Lefax, May, 1915; an abstract of an article by F. W. Ballard in the Journal of the A. S. M. E., Feb., 1915. The new municipal lighting station on East Fifty-third street, Cleveland, Ohio, went into operation July 20, 1914. The decision to build this plant was the result of experience with a small station of 1,500-kws. capacity, known as the Brooklyn Station which has been in operation by the city since 1906.

PLANT VALUE OF BROOKLYN STATION AND DISTRIBUTION SYSTEM

Bond issue 1902		$30,000.00
From taxes and general fund	$320,796.24	
Value of street lighting	109,147.02	
Added from taxes and general fund 1906–1909		211,649.22
Added from earnings		306,533.21
Investment in plant, Dec. 31, 1913		548,182.43
Depreciation written off Dec. 31, 1913		113,244.19
Depreciated value of station Dec. 31		$434,938.24

REVENUE AND EXPENSES FOR YEAR 1913

Total revenue from sale of current			$185,698.81
Kw-hr. generated ..7,797,661	Ave. sale price	$0.0238	
Kw-hr. sold 5,656,668	Ave. sale price	0.0328	
Total operation and maintenance expense			116,719.55
Kw-hr. generated ..7,797,661	Ave. cost price	$0.0149	
Kw-hr. sold 5,656,668	Ave. cost price	0.0206	
Net earnings			$68,979.26
Fixed charges — Depreciation and interest			19,079.50
Kw.-hr. generated ..7,797,661	Ave. cost price	$0.0024	
Kw-hr. sold 5,656,668	Ave. cost price	0.0033	
Profit for year of 1913			$49,899.76

POWER STATION REPORT FOR YEAR 1913

Operation		Unit cost
Labor	$23,050.25	$0.0029
Oil, packing and waste	1,538.52	
Water	3,110.00	
Sunday expense	743.32	0.0007
Coal	39,275.42	0.005
Maintenance		
Buildings	$105.85	
Boilers	3,515.98	
Engines and generators	3,449.72	
Condensors and piping	606.91	
Switchboard	153.48	
Tools	223.81	
Arc light equipment	661.88	
Sundry repairs	246.21	0.0011
Total operation and maintenance	$76,681.35	0.0097
Total kw-hr. generated	7,797,661	

DISTRIBUTION SYSTEM — OPERATION AND MAINTENANCE FOR YEARS 1912–1913

Poles and lines	$ 7,342.53	$8,203.32
Arc lamps	2,241.68	4,485.53

Meters	334.12	486.68
Tools	197.25	213,69
Wagons, harness, etc.	582.16	760.28
Stable expense, feed, etc.	1,134.86	1,935.57
Carbons and globes	2,219.08	2,735.80
Trimming labor	2,811.25	2,437.48
Services, transformers, etc.	3,224.87	6,166.62
Miscellaneous expense	573.40	1,084.94
Auto truck	....	923,61
Substation maintenance	....	2,054.98
	$20,661.20	$31,846.50
Kw-hr. generated	4,611,853	7,797,661
Cost per kw-hr. generated	$0.00448	$0.00408

The new station equipment consists of 3 turbine units of 5,000-kw. each, 1,800 rev. per min 11,000 volts A. C. supplied with steam at 225 lbs. and 125 deg. F. superheat. The boilers are installed with 10,000 sq. ft. of heating surface. They are equipped with Taylor underfed stokers and are intended to be capable of operating to 300% of rating.

The operation of the boilers at a high percentage of rating means a higher temperature of flue gases. This, with the low temperature of feed water, gives a temperature head between flue gases and feedwater which will be practically double that ordinarily obtained in economizer practice. This alone would be sufficient to warrant the installation of a larger amount of economizer heating surface. Another factor, however, is the low interest rate of 4.5% on the investment to be balanced against the saving produced in the economizers. These were installed by the Green Fuel Economizer Company and have a heating surface of 27,000 sq. ft.

The use of both forced and induced draught contributes greatly to the flexibility of the installation, and makes it possible to carry practically a balanced pressure in the combustion chamber, thus avoiding one of the greatest sources of loss in boiler practice, namely, the leakage of air through the boiler settings.

Coal is delivered overhead by railway cars, and discharged by gravity into bunkers which have a capacity of 3,400 tons. From these bunkers it is drawn through gates under pneumatic control into an electric telpher, which moves back and forth from under the bunkers on the track leading out over the stoker hoppers. The coal hopper on this telpher is carried on scale beams, and the weight of the coal and the time of delivery are carefully recorded. The power for the motor driven auxiliaries is taken from a 1,000-kw. turbine formerly in operation at the Brooklyn station, and will be operated in connection with a Le Blanc condenser, the cooling water for which will be drawn from a cistern used for the storage of the boiler feed water and which takes also the condensate from the three main turbines. The water in the cistern passes through the jet condenser several times before it goes as feedwater to the boilers and the connections are so arranged that the coldest water is supplied to the condenser and the hottest to the boiler feed system. The auxiliary motors in the station are connected through a double bus system so that each can be operated by current either

from the auxiliary turbine or the main turbine. In this way the load on the auxiliary turbine can be adjusted so that the temperature of the feed water will be that best suited for delivery to the economizers.

Tests showed that the 3 turbines were each capable of 7,500 kws. continuous capacity and the auxiliary machine, of 1,500 kws., making a total of 24,000 kws. maximum continuous capacity. The station, however, is rated at 25,000 kws. All current supplied is alternating, even in the congested districts.

The results secured in the way of operation and maintenance costs in the new power station itself for the months of August and September are shown below.

Operation	August	Unit cost	September	Unit cost
Labor	$1,498.48	$0.0018	$1,573.00	$0.0017
Switchboard attendance	352.80	0.0004	380.00	0.00042
Oil, packing and waste	.....	......	66.89	0.00008
Sundry expense	.....	......	10.46	
Coal	2,686.50	0.0033	2,415.69	0.0026
Maintenance				
Condensers, piping, etc.	5.48	......	....	......
Total operation and maintenance	$4,543.26	$0.0055	$4,446.04	$0.0048
Total kw-hr. generated	809,120	......	914,850	....

The station during these 2 months has been operating at less than .2 of its total capacity. The figures representing unit costs for the various items of labor, maintenance, fuel, etc., are, of course, considerably higher than can be obtained when the station is running up to its capacity, when it will be operating at a much higher efficiency in regard to coal consumption per kw.hr., and also the labor and other charges will be less per unit cost by reason of the larger output.

Cost of Operating City Lighting Plant in Detroit. Electrical World, April 29, 1916. The energy for the municipal lighting system in the city of Detroit is generated at a steam station which contains 1 5000-kw. and 2 2000-kw., 60-cycle, 2300-volt, two-phase Westinghouse turbo-generators with steam-driven auxiliaries. A triple expansion 800-h.p. Williams steam engine also operates a 600-kw. two-phase, 2300-volt Stanley alternator. The boiler plant contains 4 300-h.p. double-deck tubular boilers with Hawley down-draft furnaces, 1 300-h.p. Wickes vertical water-tube boiler with Detroit stoker, 3 400-h.p. Wickes vertical water-tube boilers with Taylor stokers and Foster superheaters, and 2 Sterling water-tube boilers with Taylor stokers. The coal used is Meadowbrook lump at $2.50 per ton, and nut, pea and slack at $2.25 per ton.

The city's lighting system load consists of 8193 4-amp. and 6.6-amp. series arc lamps for street lighting, and 1210 kw. of carbon incandescent lamps, 4350 kw. of tungsten incandescent lamps and 1840 h.p. in small motors and fans in public buildings. To the main station 2554 arc lamps are connected, with the re-

TABLE III. COST OF OPERATING PLANT FOR YEAR ENDED JUNE 30, 1915

	Total	Cost per kw-hr.
Maintenance:		
Buildings, track, dock, etc.	$2,397.82	
Steam plant	7,541.22	
Electric plant	3,860.33	
Miscellaneous tools and machinery	4,131.05	
Conduits	1,196.30	
Towers and lamp posts	1,787.06	
Arc lamps and switches	6,868.32	
Lines and cables	29,138.08	
	$56,920.18	$0.00329
Executive:		
Salary secretary and city electrician	$8,000.00	
Printing and stationery	848.88	
Store room	4,395.73	
Office expense	8,695.28	
Superintendence and drafting	6,881.33	
	$28,821.22	0.00166
Station:		
Oils	$481.28	0.00003
Waste	30.97	0.00000
Coal	64,375.32	0.00372
Miscellaneous supplies	1,433.08	0.00008
Wages	38,523.88	0.00222
	$104,844.53	0.00605
Lighting:		
Trimming and patrolling	$19,063.10	
Electrodes	8,618.15	
Rectifier tubes	1,721.00	
Incandescent lamp renewals	4,801.61	
Incandescent lighting expense	1,225.72	
Globes	2,471.47	
Miscellaneous supplies	49.75	
Belle Isle Park	933.85	
Palmer Park	79.20	
	$38,963.85	0.00225
Shop supplies	$40.65	
Surgeon and hospital	2,130.10	
Relief fund	4,115.61	
Total operating cost	$235,836.14	$0.01361
Total kw-hr. output at switchboard	17,327,785	

mainder connected to the distributing circuits from 5 substations. The total operating expenses for the system, according to the twentieth annual report of the Public Lighting Commission, just published, are given in table III. The kw.hr. load represented by the arc and the incandescent lamps, the total lamp-hours scheduled, the station operating costs and the coal burned per kw.-hr. for the 12 months covered by the report, are shown in Fig. 4.

Cost of Construction and Operating Expenses of the Municipal Electric Lighting Plant at Burlington, Vt. Engineering News, May 30, 1907. The municipal electric lighting plant, of Burlington, Vt., was authorized by the City Council, in 1904, and Prof. W. H. Freedman was retained as Consulting Engineer. The building con-

tract was let to a local builder on a cost-plus-10% basis. The contract for the entire steam and electric equipment was awarded to Bellman & Sanford, of 149 Broadway, New York City.

At the outset, the important question arose, whether the city could exercise the right of "eminent domain" to secure the use of existing poles in the corporate limits. The clause in franchises providing for free attachments of all municipal signal wires, was claimed as establishing precedent for free attachment of all muni-

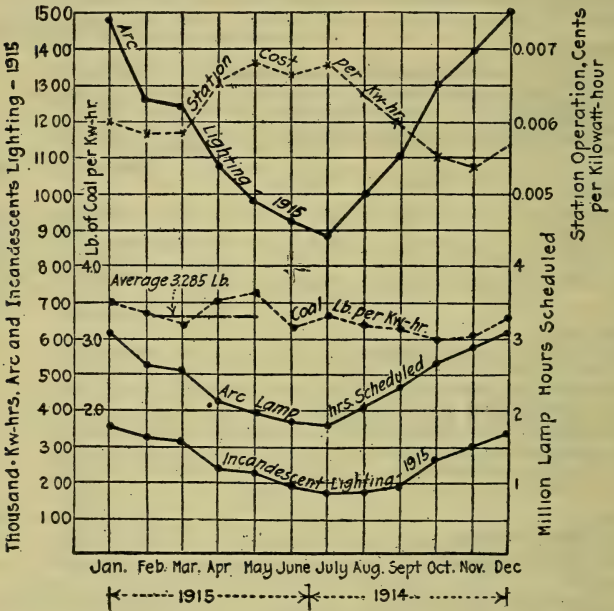


Fig. 4. Lighting load and station operating costs for Detroit City light plant.

cipal wires. However, instead of taking the question into the courts, a compromise was effected whereby the city pays a rental of 20 cts. per attachment per year.

The first equipment of the plant was in brief: 2 Atlas 150-h.p. water tube boilers; Sturtevant induced draft and economizer plant; 2 Crocker-Wheeler 125kva., 2 300-volt, alternators direct connected to Watertown, 200 h.p., 257 rev. per min., compound, slide-valve engines; 1 Wheeler jet condenser; 3 Westinghouse constant current transformers, of 100 arc capacity each; 218 Westinghouse enclosed arc lamps. The cost of this installation is segregated in Table IV.

TABLE IV. COST OF FIRST INSTALLATION

Building	$8,899.75
Machinery	20,929.12
Line and lamps	21,073.39
Consulting engineering	2,972.94
Total	$53,875.20

The service was entirely satisfactory after the plant assumed normal running condition. The lights are operated from dusk to dawn with no "moonlight schedule." Altogether 16 street and 13 commercial arcs have been added since the original plant was started, making a present total of 247 lamps on 6 circuits. There was from the first some demand for incandescent lighting service, for city buildings and by persons dissatisfied with the private service in the city; $5,000 was appropriated by the City Council and a few constant potential lines were strung, until the combined load of arc and incandescent service was such that it seemed best to install additional generating equipment to insure continuous service. In April, 1906, the contracts were let to the manufacturers, for the installation of machinery for this, at the prices shown in table V. No intermediate contractors were concerned in the work. A large amount of construction was done by the superintendent of the plant under minor contracts, and by his own force. The entire cost of the plant to Jan. 1, 1907, is given in Tables V and VI.

TABLE V. ADDITIONAL EQUIPMENT AND COSTS

1 300 hp. Atlas water tube boiler	$4,125.00
Sturtevant induced draft and economizer plant	2,200.00
1 Westinghouse 300-kw. turbine generating unit	12,369.00
1 Wheeler jet condenser for turbine	2,119.00
1 35-kw. Westinghouse rotary converter	1,114.00
Switchboard	510.00
Piping, wiring transformers and small machinery by superintendent or minor contracts	21,990.14
Total	$44,427.16

TABLE VI. SEGREGATION OF STATION COST TO JAN. 1, 1907

Buildings	$ 13,482.60
Steam equipment	29,081.01
Electrical equipment	17,081.79
Street lighting system	21,572.27
Commercial system	16,796.79
Tools and office fixtures	289.88
Total	$98,302.34
Appropriations, bond issues and premiums	$108.592.53
Unexpended balance	$10,290.19

The liabilities incurred by the city in building the plant were:

Bonds due 1934	$58,000.00
Bonds due 1936	39,000.00
Council appropriation	5,000.00
Total	$102,000.00

Of this sum $3,697.66 has never been expended and with $6,592.53, premiums on the sale of bond issues, lies at the credit of the electric light department, making a reserve capital of $10,290.19.

The operating cost of the plant for the year 1906 is given by Table VII, and the operating income, in Table VIII. A net gain of $3,931.97 over expenditures is shown, which would be 4% interest on the cost of the plant, $98,302.34. This is claimed by the Electric Light Commissioners as the profit which the plant earned, but it cannot justly be that amount. These figures follow the system of city accounting of Burlington, except that fuel on hand Jan. 1,

TABLE VII. OPERATING EXPENSES AND INCOME FOR THE YEAR 1906

Expense generating plant:	
Fuel	$7,642.41
Labor	3,467.23
Supplies	584.39
Repairs	310.48
Total	$12,004.51
Expense distribution system:	
Supplies	$116.67
Repairs	1,797.88
Labor	1,000.69
Total	$2,915.24
Administration expense:	
Office supplies, Telephone, etc.	$612.20
Salaries	1,533.33
Advertising	89.15
Interest on bonds	3,100.00
Total	$5,334.68
Grand total	$20,254.43
Operating income:	
Street lights	$16,103.33
Commercial lights	7,612.76
Accounts receivable	420.09
Supplies and labor sold	50.22
Total	$24,186.40
Net gain of income over expense	$3,931.97

TABLE VIII. COMPARISON OF INCOME AND COST FOR THE YEAR 1906

Operating income	$24,186.40
4% interest on reserve	411.61
Total income	$24,598.01
Operating cost	$20,254.43
For depreciation fund	1,981.19
Total operating expenses	$22,235.62
Balance as profit	$2,362.39
Profit in % of liabilities	2.15

1907, appearing on the city accounts as operating income is here deducted and does not appear in either expense or income tables.

The city system does not include any depreciation in value of the machinery. A charge has here been figured as that sum, which annually placed on interest at 4% will amount to $58,000.00 in 27 yrs., and to $44,000.00 additional at the end of 29 yrs. Such a sum is $1,981.19 for 27 yrs., and $798.78 for the 2 yrs. additional. At the end of these terms, the bond issues will have been met from receipts, and the plant will be entirely solvent, whatever value the machinery may have at the end of these terms. This method of figuring the profit earned by the plant seems more accurate than that of the Board of Commissioners. The earning by this is then 2.15% of the entire liability, $102,000.00.

The Board of Electric Light Commissioners is conducting an advertising campaign for its commercial service in an endeavor to place the plant on a still better paying basis. When this service was first installed the receipts were very small, but the increase has been considerable as Table IX shows.

TABLE IX. INCREASE IN COMMERCIAL SERVICE

Receipts, month of January, 1906	$377.60
Receipts, month of February, 1906	$474.53
One month's increase in per cent. of January receipts	25.5
Receipts, month of January, 1907	$1,225.10
Per cent. increase over January, 1906	223.5

Yearly Operating Costs in Four Typical Central Stations in Massachusetts. The following operating costs, from Data, November 1910, were for the year ending June 30, 1909:

GENERAL	Salem Electric Light Co.	Fitchburg Gas & Electric Co.	Haverhill Electric Co.	Malden Electric Co.
Type of prime mover	6 engines	3 engines	2 turbines 1 engine	1 turbine 3 engines
Rated station capacity, kw.	2,500	2,000	2,300	....
Output, millions of kw-hr.	3.106	4.006	3.721	4,715
Yearly load factor, %	14.2	22.9	18.5	....
Total station operating force	14	12	13	14
Cost of fuel, dol. per ton.	4.51	4.52	3.97	3.78
Coal per kw-hr., lb.	3.3	3.28	3.27	3.02
OPERATING COSTS. CTS. PER KW-HR.				
Coal	0.740	0.740	0.650	0.565
Oil and waste	0.025	0.015	0.190	0.020
Water	0.027	0.025	0.003	0.045
Wages	0.410	0.308	0.285	0.320
Station building repairs	0.034	0.017	0.063	0.023
Steam equipment repairs.	0.158	0.041	0.073	0.072
Electrical equipment repairs	0.011	0.072	0.019	0.14
Miscellaneous	....	0.024	0.040	0.21
Total	1.412	1.242	1.152	1.08

Steam-Electric Central Stations in the State of Massachusetts. Data, September, 1910, gave the following operating costs for the year ending June 30, 1908:

OPERATING COSTS. CT. PER KW-HR.

	Boston	Worcester	Lowell	Fall River	Malden	Cambridge	Lynn
Fuel	.462	.703	.710	.880	.635	.690	.618
Oil and waste	.008	.027	.009	.032	.017	.019	.012
Water	.024	.034	.008	.012	.032	.055	.040
Wages	.192	.360	.262	.538	.342	.347	.296
Station repairs	.015	.012	.020	.012	.035	.021	.052
Steam repairs	.042	.055	.020	.037	.072	.059	.147
Electrical repairs	.056	.055	.009	.029	.014	.046	.045
Miscellaneous	.023	.000	.022	.080	.033	.000	.000
Total	.822	1.246	1.060	1.620	1.180	1.237	1.210
Cost of fuel per ton	$3.99	4.79	4.75	4.68	4.49	4.40	3.60
Output millions kw.-hr. per yr.	88.5	5.4	9.4	4.0	4.6	6.0	8.7
Capacity of stations, thousands of hp.	73.5	5.90	7.39	4.43	4.87	6.75	8.2

Central Station, Operating Costs. These data are from the annual report of the Fitchburg Gas & Electric Light Co.

Gross receipts:	
Commercial lights	$ 60,230
Motors	55,291
Street lighting	35.205
Miscellaneous	2,644
Total	$153,370
Operating expenses:	
Station operation	$ 47,711
Distribution	15,791
Office	19,066
Taxes	10,399
General	7,623
Total	$100,595
Net receipt of operation	$ 52,775
General statistics:	
Station capacity in kw.	2,000
Gross income per kw. station cap.	$76.68
Connected load per kw. station cap.	1.337
Connected motor load per kw. sta. cap.	.765
Population served	37.826
Number of residences, Oct. 1, 1910	4,528
Residence consumers, Oct. 1, 1910	890
Consumers per 100 population	2.56
Residence consumers per 100 population	2.35
Average income per consumer	$158
Gross income per capita	4.05
Electric plant investment per capita	15.20
Watts station capacity per capita	53
Total investment	$574,926

Yearly operating expense per $100 invested..	17.50
Kw-hr. generated	4,461,580
Kw-hr. accounted for per 100 kw-hr. generated	89
Year load factor	30.8%

Central Station Gross Receipts. These figures for typical small stations are given by the National Electric Light Association, 1909:

LOCATION	Population	Capital	Ice	Water	Electricity and supplies	Total per capita
New Jersey	4,000	$30,000*	....	....	$10,909.42	$2.60
Illinois	1,000	$12,000	....	....	2,900.00	2.90
Kentucky	1,800	5,500† 7,500*	....	....	6,145.72	3.41
New York	1,300	12,000*	....	....	5,504.16	4.25
Ohio	1,800	20,000*	....	....	8,300.00	4.60
Illinois	2,000	10,000	....	....	7,563.98	3.78
Illinois	2,700	25,000* 12,500†	....	$720.00	8,353.80	3.36
Indiana	860	10,000	....	320.00	3,952.00	5.00
Ohio	1,900	40,000	....	3,745.00	7,235.20	6.10
Kentucky	1,900	40,000	$4,945.52	1,270.00	7,933.00	7.85
Iowa	4,000	.....	12,000.00	5,600.00 Steam h'tg.	38,300.00	14.00

* Stocks. † Bonds.

Central Station Diversity Factors and Investments. Data, January, 1911, gives the following:

TABLE X. DIVERSITY FACTOR OF THE SYSTEM

	Residence light	Commercial light	Motor service	Large users
Between consumers	3.35	1.46	1.44	...
Between transformers	1.30	1.30	1.35	1.15
Between feeders	1.15	1.15	1.15	1.15
Between substations	1.10	1.10	1.10	1.10
Consumer to transformer..........	3.35	1.46	1.44	...
Consumer to feeder	4.36	1.90	1.95	1.15
Consumer to substation	5.02	2.19	2.24	1.32
Consumer to generator	5.52	2.41	2.46	1.45
Consumer to generator corrected for losses	4.13	1.81	1.84	1.09

INVESTMENT IN DOLLARS PER KILOWATT FOR VARIOUS CONSUMERS

Meters	124	38	15	Negligible
Transformers	12	12	12	8
Distributing lines	146	146	145	49
Substations and transmission	58	58	58	58
Generating equipment	100	100	100	100
Total investment	440	354	330	215

Operating Costs and Income. The tabulation from Bulletin 38. Iowa State College Engineering Experiment Station, gives some average figures dealing with costs and incomes per kilowatt hour for commercial electric central stations. The group numbers are based on population as follows: Group I, 500–2,000; II, 2,000–3,000; III, 3,000–10,000; IV, 10,200–20,000; V, 20,000–117,000.

TABLE XI

Group number	Number of stations	Average population	Average kw. rating of station	Average annual kw-hrs. made per station	Average expense per kw-hr. made, cts.	Average gross income per kw-hr. made, cts.	Ave. ratio, expense to gross income, %
I	18	1,290	86	78,000	7.8	10.3	75.8
II	7	2,640	154	230,000	4.9	6.8	72.6
III	11	5,680	489	540,000	4.8	7.2	66.1
IV	4	12,690	1,225	1,820,000	2.5	4.6	54.6
V	6	46,830	4,130	7,700,000	1.8	3.9	47.1
All groups.	46	9,470	819	940,000	5.2	7.6	67.8

Operating Expenses of Massachusetts Steam Stations. The data given in Table XII and taken from Electrical World, August 7, 1915, represent an analysis of the officially reported operating expenses of steam-electric stations in the State of Massachusetts that generated or purchased more than 5,000,000 kw-hrs. of electrical energy during 1914. The figures are based upon the returns of companies made to the Board of Gas and Electric Light Commissioners. On account of the fact that a number of the companies purchase and distributed energy in addition to the output of their stations, the operating expenses are divided into those due to station operation and those due to distribution. All expenses are given in cents per kw.-hr. so that the relationship of the various items in any one plant can be easily found. When comparing the same items of different stations, such as wages, office management, taxes and the like, it must be remembered that the relative magnitude of the station outputs must be considered in order to make a fair comparison.

Of the 20 stations for which data are given, 12 are in cities of from 40,000 to 100,000 people and have a station output varying for the most part between 5,000,000 kw.-hrs. and 15,000,000 kw.-hrs. per annum. It is interesting to note that the total output for the stations reported excluding Boston in 18 cities of a total population of 1,194,870 is 209,250,000 kw.-hrs., which is only 20,530,000 kw.-hrs., or 10%, more than the reported annual output of the Boston company in a city of 670,585 people. The averages given in next to the last column for the operating costs of the preceding 19 stations are interesting when compared with the costs for the Boston company. The figures in the average column represent in a general way the average of conditions as regards operating costs for stations similar in size and yearly output when varying conditions as regards plant-factor and load-factor are ignored. The cost data for the Boston company, on the other hand, represent results of a highly specialized system operating under conditions which favor reduced costs per kilowatt-hour. This is particularly noticeable in the cost of fuel, wages and station repairs, these values being lower than the average of the values for the other stations of the State.

TABLE XII. OPERATING EXPENSES FOR 1914 OF MASSACHUSETTS STEAM STATIONS OF AN ANNUAL OUTPUT OF MORE THAN 5,000,000 KW.-HR.

	Cambridge	East-hampton	Brockton Edison	Fall River	Fitch-burg	Green-field	Haver-hill
Type of prime mover	Turbines	Turbines and engines	Engines	Turbines	Turbines and engines	Turbines	Turbines and engines
Station equipment rating in kw.	7400	4050	10,926	10,000	4800	5491	4950
Output in million kw-hr.	12.40	2.40	13.99	13.57	7.11	7.70	6.93
Cost of coal, dollars per ton	3.93	4.28	4.65	3.93	4.33	4.45	4.78
Coal per kw-hr. in lb.	2.54	3.15	3.05	2.51	4.07	*	3.07
Population in thousands	104.84	8.52	56.87	119.29	37.82	10.42	44.11
Operating expenses due to station operation in cents per kw-hr. made:							
Coal	0.447	0.602	0.635	0.441	0.795	*	0.655
Oil and waste	0.013	0.006	0.006	0.006	0.013	*	0.013
Water	0.028	0.002	0.001	0.013	0.030	*	....
Wages	0.345	0.327	0.235	0.135	0.237	0.170	0.202
Station repairs	0.030	0.001	0.026	0.018	0.017	0.010	0.012
Steam equipment repairs	0.033	0.111	0.056	0.014	0.018	0.018	0.058
Electric equipment repairs	0.030	0.020	0.011	0.045	0.001	0.026	0.008
Tools and appliances	0.004	0.004	0.019	0.014	0.016	0.003	0.018
Operating expenses due to distribution in cents per kw-hr. sold:							
Repairs and renewals:							
Lines and conduits	0.063	0.049	0.136	0.064	0.054	0.151	0.123
Meters, lamps and motors	0.010	0.006	0.030	0.042	0.009	0.078	0.056
Wages	0.484	0.006	0.176	0.210	0.116	0.131	0.136
Miscellaneous	0.194	0.001	0.214	0.22	0.078	0.013	0.243
Expenses of office management	0.251	0.052	0.547	0.500	0.034	0.315	0.623
Taxes	0.468	0.072	0.378	0.355	0.286	0.189	0.407
Net operating income	1.942	0.364	1.400	1.533	1.114	1.159	1.966

* Operates hydroelectric and steam stations.

TABLE XII.—*Continued.*

	Holyoke	Lawrence	Lowell	Lynn	Malden	New Bedford	North Adams
Type of prime mover	Turbines	Engines	Engines	Turbines and engines	Turbines and engines	Turbines	Turbines and engines
Station equipment rating in kw.	6700	10,942	5400	6650	3400	11,550	2000
Output in million kw-hr.	13.94	6.82	12.78	12.00	10.06	6.28	5.25
Cost of coal, dollars per ton	4.79	4.80	4.58	3.73	4.60	3.94	4.30
Coal per kw-hr. in lb.	*	*	3.07	2.86	3.16	3.86	3.34
Population in thousands	57.73	85.89	106.29	89.33	44.40	96.65	22.00
Operating expenses due to station operation in cents per kw-hr. made:							
Coal	*	*	0.629	0.476	0.642	0.680	0.638
Oil and waste	*	*	0.009	0.013	0.010	0.008	0.003
Water	*	*	0.004	0.030	0.057	0.039	0.069
Wages	0.204	0.348	0.195	0.198	0.184	0.437	0.204
Station repairs	0.004	0.056	0.016	0.054	0.005	0.030	0.021
Steam equipment repairs	0.044	0.018	0.066	0.142	0.059	0.051	0.062
Electric equipment repairs	0.010	0.017	0.021	0.012	0.011	0.020	0.022
Tools and appliances	0.003	....	0.015	0.003	0.016	0.011	....
Operating expenses due to distribution in cents per kw-hr. sold:							
Repairs and renewals:							
Lines and conduits	0.141	0.404	0.099	0.573	0.446	0.494	0.035
Meters, lamps and motors	....	0.145	0.035	....	0.037	0.211	0.025
Wages	0.113	0.148	0.314	0.249	0.282	0.394	0.076
Miscellaneous	0.073	0.192	0.213	0.168	0.453	0.255	0.063
Expenses of office management	0.098	0.484	0.524	0.246	0.586	0.356	0.425
Taxes	....	0.530	0.500	0.560	0.443	0.441	0.180
Net operating income	1.153	2.925	1.637	2.221	1.887	1.898	1.412

* Operates hydroelectric and steam stations.

TABLE XII.—*Continued.*

	Pittsfield	Salem	United Springfield	Worcester	Worcester Suburban	Average Values Excluding Boston Edison	Boston Edison
Type of prime mover	Turbine, Diesel and steam engines	Turbines and engines	Turbines	Turbines	....	....	Turbines
Station equipment rating in kw....	2990	4500	19,025	14,620	7730	....	101,400
Output in million kw-hr.	5.04	9.18	26.91	30.03	6.86	....	188.72
Cost of coal, dollars per ton.......	3.70	4.21	4.33	4.18	4.39	4.09	3.92
Coal per kw-hr. in lb.	*	2.71	*	.254	2.80	3.05	2.12
Population in thousands	32.12	43.69	88.92	145.98	....	....	670.58
Operating expenses due to station operation in cents per kw-hr. made:							
Coal	*	0.511	*	0.474	0.364	0.570	0.373
Oil and waste	*	0.007	*	0.004	0.002	0.008	0.002
Water	*	0.017	*	0.001	0.001	0.022	0.011
Wages	0.416	0.166	0.137	0.104	0.092	0.216	0.150
Station repairs	0.013	0.009	0.015	0.035	0.002	0.018	0.006
Steam equipment repairs	0.075	0.054	0.044	.062	0.009	0.051	0.032
Electric equipment repairs	0.002	0.006	0.031	0.017	0.002	0.015	0.064
Tools and appliances	0.007	0.008	0.003	0.001	0.012	0.008	0.018
Operating expenses due to distribution in cents per kw-hr. sold:							
Repairs and renewals:							
Lines and conduits	0.138	0.113	0.079	0.158	0.076	0.170	0.315
Meters, lamps and motors.......	0.227	0.031	0.022	0.016	0.020	0.055	0.120
Wages	0.549	0.150	0.206	0.082	0.052	0.198	0.025
Miscellaneous	0.173	0.215	0.077	0.079	0.021	0.147	0.197
Expenses of office management....	0.389	0.405	0.321	0.349	0.090	0.344	0.701
Taxes	0.305	0.287	0.312	0.198	0.059	0.314	0.602
Net operating income	1.848	1.212	1.664	1.592	0.918	1.492	2.314

* Operates hydroelectric and steam stations.

The cost of repairs to electrical equipment, tools and appliances and repairs to lines is, however, higher for Boston than the average of the values for other stations of the State, as might be expected. In addition, the cost of management and taxes for the Boston station is more than twice the average value for the State, yet the net operating return per kw.-hr. for Boston is 1.5 times that for the State. In the case of the Boston company taxes per kw.-hr are considerably more than the cost of coal per kw.-hr., while for the entire State the item of taxes is about equal to the cost of coal.

The averages for the stations of the State show the cost of fuel to be about 70% of the total station operating expense, wages to be 26%, with the remaining percentage accounted for by oil, waste, water, tools and repairs.

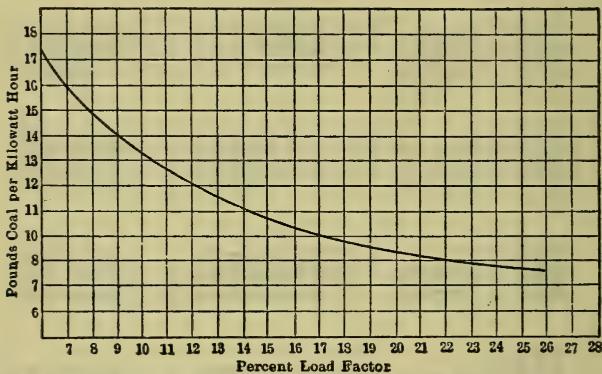


Fig. 5. Relation of coal consumption and load factors.

TABLE XIII. GENERATING COSTS FOR MIDDLE WEST STEAM STATION

General expenses	Amount	% of total operating expenses
Superintendence	$ 2,109.16	1.63
Boiler labor	5,287.06	4.11
Engine labor	4,042.77	3.13
Miscellaneous labor	59.06	0.05
Fuel	47,224.39	36.65
Water	8.60	0.01
Lubricants	327.63	0.25
Production supplies	309.87	0.24
Station expense	611.97	0.48
Repairs steam equipment	10,008.49	7.76
Repairs electrical equipment	209.96	0.16
Repairs station, buildings, structures and miscellaneous	303.92	0.24
Total generating expenses	$70,502.88	54.71

TABLE XIV. EXPENSES OF THE DISTRIBUTION SYSTEM

General expenses	Amount	% of total operating expenses
Superintendence	$100.05	0.08
Wages	165.65	0.13
Setting and removing meters	969.45	0.75
Setting and removing transformers	437.70	0.34
Supplies and expenses	1,500.73	1.16
Repairs overhead lines	7,436.87	5.77
Repairs underground system	197.02	0.15
Repairs services	1,035.24	0.80
Repairs distribution transformers	308.97	0.24
Repairs customers' meters	3,549.51	2.75
Total distribution expenses	$15,701.19	12.17

Generation and Distribution Expenses of a Middle West Company. The data in tables XIII and XIV taken from Electrical World, January 13, 1917, show the annual generation and distribution expenses of an electric service company operating in a Middle West city of 50,000 inhabitants, and having 5500 consumers. Last year the maximum demand was 4400 kws. and the annual output 11,920,000 kw.-hrs.

OPERATING EXPENSES PER KW-HR. GENERATED FOR SMALL WISCONSIN STEAM STATIONS

Station location	Population	Generation, kw-hr.	Classified expenses, cts. per kw-hr. Generation	Distribution	Consumption	Commercial	General	Undistributed	Total
Algoma	2,300	97,580	3.36	0.25	0.10	...	1.20	0.03	4.94
Alma	1,100	29,382*	8.24	0.35	0.15	0.07	0.28	0.45	9.54
Arcadia	1,400	87,550	4.86	0.39	0.29	...	0.40	0.09	6.03
Athens	1,200	103,920	4.17	0.13	0.29	0.03	0.28	0.04	4.94
Cedarburg	2,000	198,231	4.41	0.60	0.07	0.12	0.22	...	5.42
Chilton	1,800	175,400	5.86	0.64	0.30	...	0.74	...	7.54
Gillett	800	24,400	3.01	3.53	0.12	...	0.08	...	6.74
Mondovi	1,325	*30,000†	7.41	0.11	0.70	0.51	1.27	0.70	10.70
Omro	1,100	38,100	5.98	0.94	0.79	0.85	2.78	0.30	11.64
Neillsville	2,000	75,000	5.61	1.02	0.68	...	0.40	...	7.71
Owen	800	141,720	§1.43	1.16	0.20	0.08	0.35	0.04	3.26
Pardeeville	1,050	43,200†	5.03	0.83	2.95	0.14	0.60	0.07	9.62
Phillips	2,500	250,000‡	3.54	0.20	0.11	0.08	1.77	0.10	5.80
Rib Lake	1,100	37,880	7.27	0.57	1.36	...	...	...	9.20
Rio	700	22,000‡	9.18	0.18	0.45	...	2.73	...	12.54
Sauk City	900	34,500	6.81	0.25	0.27	...	...	...	7.33
Seymour	1,100	45.400	8.78	0.86	0.23	...	0.27	...	10.14
Sheboygan Falls	1,630	65,000	4.29	1.25	4.11	0.03	1.85	...	11.53
Viroqua	2,200	148,600	3.45	0.67	0.13	...	0.11	0.23	4.59
Bangor	750	55,500	5.84	0.16	0.04	0.58	0.01	...	6.63
Weighted average	......		4.68	0.62	0.48	0.09	0.76	0.08	6.71
Arithmetic average	......		5.42	0.70	0.66	0.13	0.77	0.10	7.78
Median	......		5.32	0.58	0.28	0.10	0.40	0.10	7.44

* Estimated. † Mostly purchased at 3 cents. ‡ Both steam and hydraulic generation. § Burns mill refuse for fuel.

The utilization, commercial, general and miscellaneous expenses amounted to about 5, 14 and 14% of the total, respectively. Fuel, 36.65%; repairs to steam equipment, 7.76%; boiler labor, 4.11% and engine labor, 3.13% constituted the larger items under generation expense, while repairs to overhead lines, 5.77% and repairs to customers' meter, 2.75%, made up the principal part of distribution cost.

Unit Operating Expenses of Several Small Wisconsin Utilities. The following data from Electrical World, March 11, 1916, collected by the Wisconsin Railroad Commission on the operating expenses of 20 small electric utilities serving communities of 2500 persons and less, are tabulated herewith according to the classification of accounts prescribed in most States. It may be pointed out that the cost of generating energy in these particular cases is about 70% of the total cost of supplying electric service. Next in order are the expenses of general supervision 11%, of distribution 9%, and of utilization 7%. In the plants having annual outputs of 50,000 kw.-hrs. or less the unit generating expense lies between 5.03 cts. and 9.18 cts per kw.-hr., but in the stations having larger outputs the unit costs are lower, making the arithmetical average cost 5.42 cts. and the weighted average 4.68 cts. per kw.-hr.

Cost of Power. The following costs were compiled from figures published in Data, 1910, 1911 and 1912.

TYPICAL 575 KW. STATION IN MASSACHUSETTS

Output at busbars, kw-hr.	656,880
Tons of coal used	2,417
Price of coal,. per ton	$4.88
Costs per kw-hr.	Cents
Coal, bituminous	1.796
Oil and waste	0.055
Water	0.038
Wages	0.724
Repairs, station building	0.107
Repairs, steam equipment	0.102
Repairs, electrical equipment	0.066
	2.888

TYPICAL 725 KW. STATION

Output at busbars, kw-hr.	889,760
Tons of coal used	2,299
Price of coal, per ton	$5.31
Costs per kw-hr.	Cents
Coal	1.372
Oil and waste	0.025
Water	.008
Wages	0.750
Repairs, station building	0.045
Repairs, steam equipment	0.130
Repairs, electrical equipment	0.003
	2.333

POWER PLANT OF THE HYDE PARK ELEC. LT. CO.

Total generator capacity, kw.	1,775
Output at busbars, kw-hr.	4,357,648

Of the total amount sold 88.5% was for street railway service.
Price of coal, per ton, bituminous, $3.94; #3 buckwheat, $3.17.

Costs per kw-hr.	Cents
Fuel	0.785
Oil and waste	0.017
Water	0.016
Station wages	0.221
Repairs, station building	0.107
Repairs, steam equipment	0.068
Repairs, electric equipment	0.015
Minor tools	0.018
	1.154

OPERATING RESULTS FROM A CENTRAL STATION USING COMPOUND CORLISS ENGINES

Rated capacity, kw.	5,000
Output at busbars, kw-hr.	6,052,518

Costs per kw-hr.	Cents
Fuel	0.633
Oil and waste	0.015
Water	0.069
Wages at station	0.302
Repairs, station building	0.074
Repairs, steam equipment	0.266
Repairs, electric equipment	0.060
	1.419

TYPICAL 5000 KW. STATION

Output at busbars, kw-hr.	8,216,267

Costs per kw-hr.	Cents
Fuel	0.544
Oil and waste	0.014
Water	0.049
Wages at station	0.282
Repairs, station building	0.075
Repairs, steam equipment	0.173
Repairs, electric equipment	0.065
	1.202

TYPICAL 6000 KW. STATION

Output at busbars, kw-hr.	8,776,165

Costs per kw-hr.	Cents
Fuel	0.617
Oil and waste	0.012
Water	0.040
Wages at station	0.296
Repairs, station building	0.052
Repairs, steam equipment	0.147
Repairs, electric equipment	0.046
Station tools & sundries	0.002
	1.212

Comparison of Costs of Operation of Gas Engine Station and Steam Generating Station. The following is taken from an article by H. S. Knowlton, Engineering Record, March 27, 1909. The

service requirements at each of these two stations, a gas-engine station at Somerville, Mass., and a steam generating plant at East Boston, are somewhat similar, both being located in outlying parts of the Boston Elevated Railway Company's system, and operated in harmony with other stations of larger size located nearer the center of the surface car, subway, tunnel and elevated railway load. All the stations of the Boston system are directly controlled in their daily operation by a superintendent of power distribution, reporting to the superintendent of power stations. In examining the records of any particular plant it is necessary, therefore, to appreciate that the needs of the system as a whole are considered before those of any particular station, and that in the handling of the company's service it is frequently necessary to impose conditions upon individual plants which do not enable the equipment to be operated at its highest local efficiency. This is in some measure the case with the stations at Somerville and East Boston.

The equipment of the Somerville plant consists of 2 two-cylinder, 32 by 36-in. American Crossley four-cycle gas engines of 610 b.h.p. rating each, running at 140 rev. per min., and each direct connected to a 350-kw., 575-volt d. c. Crocker-Wheeler generator. There are 2 Loomis-Pettibone bituminous coal down-draft producers, each 9 ft. in diam. and various auxiliary apparatus for scrubbing and cleaning the gas, circulation of water through jackets, etc. The engines are started by a 6 by 8-in. Rand air compressor. The producers are supplied with coal by hand firing, the fuel being hoisted to the charging floor by a motor-driven bucket elevator.

At East Boston the plant consists of 4 180-h.p. Corliss vertical boilers rated at 180 h.p. each, and 3 200-kw. generating sets consisting of 12 and 22 by 42-in. cross compound horizontal condensing Greene engines, direct connected to 575-volt direct current generators running 120 rev. per min. This station is hand fired and runs under natural draft.

The labor requirements at Somerville during the year were as follows: 1 chief engineer, 2 watch engineers, 2 oilers, 2 producer men, 1 coal handler, 1 helper and 1 apprentice; total 10 men. Between June 1 and Oct. 1 the force was reduced by the dropping of the helper and one producer man.

The East Boston labor requirements were: 1 chief engineer, 1 watch engineer, 2 oilers and 3 firemen; total, 7 men.

The hours of daily service at Somerville averaged from 7 A. M to 10 P. M. and at East Boston from 6.30 A. M. to 10 P. M., except in June, July and August, when the service averaged from 6.45 A. M. to 9 A. M., and from 2 P. M. to 9 P. M., Sunday operation being from 2 P. M. to 11 P. M. the year through.

The plant of Somerville operated for the year as a whole at a total manufacturing cost of 1.68 cts. per kw.-hr., exclusive of any fixed charges. (Table XV.) The coal consumption per kw.-hr. of output was 2.236 lbs., giving 1.66 lbs. per horse-power-hour of station output, all fuel included. This was the lowest fuel consumption per kw.-hr. reached during the year by all stations on the Boston Elevated system, and also the lowest fuel cost per kw.-hr.

TABLE XV. OPERATING RESULTS FOR YEAR ENDING SEPT. 30, 1908.

Location	Steam plant East Boston	Gas engine plant Somerville
Total kilowatt-hours	2,108,521	1,182,900
Total kilowatt-hours used in station	21,529	133,118
Total kilowatt-hours output	2,086,992	1,049,782
Tons of coal	3,609.2	1,048.5
Price per ton	$3.801	$4.179
Pounds of coal	28,086,193	2,348,031
Pounds of coal per kilowatt-hour	3.874	2.236
Cubic feet of water	1,163,300	265,860
Price per 100 cubic feet	$0.123	$0.126
Pounds water (evaporated) per pound coal	8.991	....
Pounds water consumed per pound coal	....	7.119
Gallons of cylinder oil	960	197.52
Price per gallon	$0.262	$0.299+
Gallons of engine oil	311.40	5,672.39
Price per gallon	$0.141	$0.15
Cost of Supplies —		
Coal	$13,721.35	$4,381.12
Cylinder oil	$252.21	$59.26
Engine oil	$44.13	$850.87
Other lubricants	....	....
Total lubricants	($296.34)	($910.13)
Water	$1,432.53	$337.34
Miscellaneous small supplies	$403.26	$1,284.65
Supplies and expenses for repairs (electrical)	$860.42	$525.32
Supplies and expenses for repairs (steam power equipment)	$2,107.25	....
Supplies and expenses for repairs (gas power equipment)	....	$1,731.74
Expenses for repairs of buildings	$112.60	$367.47
Total cost of supplies	$18,933.75	$9,537.77
Cost of coal per kilowatt-hour for year	$0.0065+	$0.0041+
Cost of supplies per kilowatt-hour for year	$0.0090+	$0.0090+
Cost of Labor —		
Engineers	$1,096.21	$1,294.60
Oilers	$1,364.25	$1,143.78
Firemen and producer men	$2,582.81	$1,119.58
Coal and ash handlers	....	$571.60
Miscellaneous, including helpers and cleaners	$372.16	$1,324.63
Labor for repairs (electrical equipment)	$83.07	$101.67
Labor for repairs (steam equipment)	$840.97	....
Labor for repairs (gas power equipment)	....	$2,544.69
Total cost of labor	$6,339.47	$8,100.55
Cost of labor per kilowatt-hour	$0.0030+	$0.0077+
Total cost of output	$25,273.22	$17,638.32
Cost of output per kilowatt-hour	$0.01210+	$0.01680+

in all plants owned by the company. Considering the fact that the capacity of the Somerville station is but 700 kw. at normal load, these figures show that the gas plant in this installation is efficient, although the load factor of the installation is unfavorable to the

highest economy of operation. The load factor defined by the full load output for 365 days at 18 hours per day divided into the actual output was 22.7% for the year. The relatively small station output for the year in relation to the machinery capacity installed tended to carry the labor cost per kw.-hr. to rather high figures, the average for the year being 0.77 cts. The high cost of labor in June, 1908, was due to the fact that at this time the station was shut down for 2 weeks' thorough overhauling, the labor of the latter being performed by the regular operating force, which brought the kw.-hr. charge to 2.23 cts. In the other summer months low output was largely responsible for the relative high labor costs, the fuel consumption running not far from that of other months when the demand on the plant was greater.

At Somerville the lowest coal consumption per kw.-hr. was obtained in August, 1908, 1.967 lbs., a month when the station output was unusually low in quantity. The figures show that this station was not much affected in fuel economy when the output dropped considerably, and a factor in this was the careful operation of the machinery only under conditions when the service of each unit was clearly necessary. In other words, if the load factor of the station were available, figured on the basis of the capacity of the equipment in actual operation at all times, it would run much higher than was indicated by the load factor quoted above. During the year the cost of coal per kw.-hr. averaged 0.41 ct., and varied from a maximum of 0.46 ct. to a minimum of 0.33 ct.

The figures for labor cost of repairs include the work done by the station staff during the annual overhauling of the producers and their auxiliaries in June. The plant has proved thoroughly reliable and has sustained no enforced shut-downs. The machinery can be started up throughout the entire station inside of 15 or 20 minutes without trouble. The losses from banking the fires are exceedingly small. The most important items of expense in the electrical end of the station in the year covered were a new switchboard panel installed for use with a plan for starting the engines by running the generators as motors, 3 new armature coils in one generator, and the re-wiring of the station lighting circuits. In the gas end of the plant the main items of expense for renewals were a cylinder head costing about $400, a new exhaust box and a new exhaust valve; while in the gas house the changing of the stones in the scrubber equipment from 6 to 2 ins. diam. was the principal alteration. The fires are cleaned and the ashes thoroughly removed on Sundays by an average force of 6 men. The average life of igniter points is about 3 months. Under ordinary conditions the gas engine exhaust valves are ground once in two months. The cylinders were cleaned formerly about every two weeks, but since changing the stones in the scrubbers this cleaning has to be done but once in 2 months. New excelsior is placed in the dry scrubber once in 2 months. New excelsior is placed in one grid of the wet scrubber each week. The point of greatest consequence appears to be to secure clean gas. An average analysis of the gas obtained is as follows: CO_2, 3 9%; O, 0.2%; CO, 24.3%;

CH_4, 1.1%; H, 7.5%; N, 63%; total, 100%. The average calorific power of the gas per cubic foot is 114.6 B.t.u. The earlier troubles from back firing and pre-ignition have now been practically overcome.

The East Boston station had a generating cost of 1.21 cts. per kw.-hr. for the year on a station load factor of 53% obtained by dividing the total year's output by 600 kws. carried 18 hrs. per day and 365 days. The average cost of coal per ton for the year was about $3.80, or 37 cts. per ton less than at the Somerville station. The coal consumption per kw.-hr. was 3.87 lbs., or about 74% greater than in the gas plant. The cost of coal per kw.-hr. for the year averaged 0.65 ct. Including all supplies the cost per kw.-hr. was the same in each station, or 0.9 ct., but the larger output of the steam plant and the smaller force tended to give it an advantage on the side of the labor cost per unit of output. In comparing these stations in this way the object is rather to show the actual results of different conditions of operation, and to emphasize the influence of operating at a good deal below the capacity of the installation. The labor cost of 0.30 ct. per kw.-hr. at East Boston was the result of a range in monthly costs from 0.21 to 0.5 per unit. In general, as the output fell off the labor cost increased. There were no breakdowns, and the only large repairs were the refitting of the boilers with new tubes.

Table XV gives the operations of the two stations for the year in full detail. In the operation of the plants of the company monthly records of cost are kept for all the items listed in the table.

Central-Station Labor Costs. The following data were taken from Electrical World, Nov. 16, 1912. *In Plant A,* serving a New England manufacturing city, the station output at the switchboard in 1911 was 2,418,000 kw.-hrs. and the labor cost for the entire year $11,265, or 0.46 ct. per unit. The payroll covered 4 engineers, 3 oilers, 3 firemen and 2 helpers, or 12 men in all, the generating plant consisting of 3 alternators of 2000-kw. combined rating, each directly driven by a vertical cross-compound engine. The units were rated at 400 kws., 600 kws. and 1000 kws., and steam was supplied by 5 Sterling boilers rated at 1250 h.p. total. The ratio between station rating and labor requirements was 166 kws. per man. The use of vertical engines, comparatively small powered units and hand firing tended to increase the labor expense. In this plant 1,494,000 kw.-hrs. were purchased during the year from an outside hydraulic transmission company at a cost of $8,434. It appears probable that if this plant were to be rebuilt in a similar situation, the labor cost could be cut materially by the installation of either a 2000-kw. turbine or 2 turbo units of possibly 1500-kw. and 500-kw. rating in place of the vertical engines. The plant is not hampered by high real-estate costs. At the time it was erected the possibility of purchasing energy at a later date was not known, and consequently 3 sizes of engines were installed to enable the owners to operate the equipment economically under widely varying loads.

Station B, rated at 4000 kws. and serving a population of about

60,000, produced electricity last year at the low labor cost of 0.17 ct. per kw.-hr. In this station the payroll covered 4 engineers, 3 oilers, 1 electrician, 5 firemen and 2 repair men, their wages totaling $16,197 for the year. The labor ratio was 210 kw. per man, and mechanical stokers were used in the boiler plant. The latter consisted of 4 525-h.p. water-tube units. The large output of the plant, 9,400,000 kw.-hrs., is chiefly responsible for the low unit labor cost.

Plant C shows the importance of large outputs in securing low unit costs, and produced electricity during a recent year at a labor cost of 0.16 ct. The installation is a tidewater plant, with mechanical fuel-handling and stoking systems, and the output for the 12 months was 14,453,000 kw.-hrs. The equipment was 6 520-h.p. water-tube boilers, 2 500-kw. turbo units, 1 200 kw., 2 1000-kw. and 1 2000-kw. engine-driven set. The station rating was therefore 5200 kws., or 192 kws. per employee on the payroll. There were 27 station men, including 4 engineers, 4 firemen, 2 helpers, 2 water tenders, 2 switchboard men, 2 repair men, 5 oilers, 1 cleaner, 1 conveyor man, 3 coal handlers and 1 clerk. This station supplies energy for lighting, motor and railway service over a large number of towns within a radius of 60 miles of the plant, and the labor requirements are unquestionably increased by the variety of circuits and voltages, including both direct current and alternating current, fed from the central installation. The gradual introduction of turbo units and the use of motor-operated valves are tending to facilitate the handling of the steam end of the plant with fewer men. The station has been in service from 10 to 15 years, and if a new plant of the same size were to be built to-day on the same site, there is little question that it could be greatly simplified, with substantial reduction in the force required to man the machinery.

Plant D, which has recently been turned into a substation following the supply of energy from a new installation, illustrates to a marked degree the tendency which diversified equipment of moderate size has to multiply labor costs. This station contained 12 hand-fired horizontal return tubular boilers and no less than 5 electric generating units of the steam-driven type, besides several motor-generators and a number of units belt-driven from a basement line shaft. The approximate rating was 4500 kws., and the payroll called for 21 men. The boiler-room work was handled by 5 firemen in spite of the absence of mechanical stokers, but on the prime-mover and generator side of the station 4 engineers and 12 other attendants were required. The cost of labor for the year was $19,571, or 0.34 ct. per kw.-hr. at the bus, the output for the year being 5,754,000 kw.-hrs. An analysis of the operating conditions in the station showed that the boilers and engines were well handled but that the multiplied labor requirements were largely due to the use of line shafting and driving small generators in addition to the main alternators, to the use of small arc-lighting dynamos and to the distribution of an extensive direct-current service for motor operation. The station building was so large that the small ma-

chines in service were greatly scattered, and the area of the plant militated against economical labor service. The rating per man was 214 kws.

Station E. Small output handicaps a station even where its general design favors economical work by its operating shifts. A typical case is afforded by Station E, equipped with 3 engine-driven alternators of 150-kw., 300-kw. and 800-kw. rating. The boiler plant consists of 4 water-tube units of 1000-h.p. combined rating, with hand firing. The station is simple in lay-out, with short distances between apparatus units, direct lines of piping and a moderate-cost switchboard. 4 engineers, 4 firemen and 1 helper are required, the rating per employee being 139 kw. In a recent year the plant output was 1,602,000 kw.-hrs., the labor cost being $7,759, or 0.48 ct. per kw.-hr.

Station F. Another small station with a more complicated equipment had a relatively high labor cost. This plant had on its payroll 7 men, consisting of 3 engineers, 1 electrical operator, 1 generator attendant and 2 firemen, and was equipped with 4 water-tube boilers of 678-h.p. combined rating, two horizontal cross-compound condensing engines, a 500-kw. turbine and 3 arc machines. The station rating was 1082 kws., or 155 kws. per employee. The labor cost for the year was $8,972, or 0.61 ct. per kw.-hr., the total output being 1,466,000 kw.-hrs. In this station the piping and auxiliaries were unusually complicated in arrangement, the floor levels were not well planned, and extreme crowding characterized the equipment in the engine room. The labor cost in this plant was unduly high, and a betterment study would probably result in a reduction of the force by about 28%. In so small a station there are great disadvantages in maintaining attendants for purely electrical duties in addition to those required to operate engine and turbine equipment and look after the general condition of the auxiliaries.

Data of the above character drawn from actual practice show some of the reasons why the large turbine plant with individual units of high power is making such inroads into the field formerly occupied exclusively by stations composed of generating and auxiliary apparatus of diversified character and low individual output. Apart from the questions of fuel economy which bulk so large in plant design and the selection of machinery for production, it is coming to be realized that enormous increases in output can be handled without additions to the number of men required to operate the installation, if the problem is viewed in a broad way. Frequently the capacity of a moderate-sized plant can be practically doubled by this means with little or no addition to the force of employees. Repeated analyses of production costs in stations rated at from 3000 kws. to 7000 kws., under favorable conditions of machinery arrangement, indicate that with the natural development of business a labor cost of 0.1 ct. to 0.15 ct. per kw.-hr. should be attained in regular practice, although 2 or 3 times that unit expense at present is a common figure.

Table XVI gives a summary of the costs for the various stations.

TABLE XVI. SUMMARY OF LABOR COSTS

Plant	Total rating of station in kw.	Annual output in kw-hr.	Number of central station employees	Kw. rating per employee	Labor cost in cents per kw.-hr.
A	2000	2,418,000	12	167	0.46
B	4000	9,400,000	15	210	0.17
C	5200	14,453,000	27	192	0.16
D	4500	5,754,000	21	214	0.34
E	1250	1,602,000	9	139	0.48
F	1082	1,466,000	7	155	0.61

2200 Volts Versus 13,200 Volts for Rural Extensions. In Table XVII are the overhead charges which may be assessed on isolated transformers when they are energized all the time, given in Electrical World, Dec. 9, 1916. The first group of figures relates to 13,200-volt equipment and the second to 2200-volt apparatus. These data indicate that if rural communities are not far from cities having electric service it may be cheaper to operate and maintain 2200-volt extensions to the city primary circuits than to operate a 13,200-volt line and corresponding voltage transformers. For instance, the overhead charges on a 5-kw. 2200-volt transformer is over $26 less than for a similar size 13,200-volt transformer with the necessary protective apparatus. Assuming interest at 7% and line depreciation, operation, maintenance and taxes at 6%, the saving on each 5-kw. transformer is sufficient to cover the overhead charges of a 2200-volt line costing $200.

This seems to indicate that for every 5-kw. transformer to be connected the 2200-volt transmission line can cost $200 more than a 13,200-volt line would to serve the same load with the same line loss, without making the overhead charge greater than for the higher voltage line. In other words, if the single-phase 13,200-volt line required to serve a scattered rural load of 5 5-kw. transformers cost $7,600, a 2200-volt line having no greater overhead charge would cost $8,600. If the 2200-volt line could not be built for this amount without obtaining a larger line loss than on the 13,200-volt line, then the higher voltage transmission would be preferable.

Distribution-Line Economies. The following is abstracted from an article in Electrical World, June 9, 1917. Some interesting views on considerations influencing selection of transformers were brought out in a recent paper, by S. B. Hood of the Minneapolis (Minn.) General Electric Company. Since the price per kilovolt-ampere of transformer rating decreases as the size increases it naturally follows that the larger sizes should be used wherever practicable. This can be accomplished usually by stringing heavier and longer secondary bus lines and feeding them with a smaller number of units. The most economical balance is obtained as regards initial investment when the cost of secondary bus lines plus transformers is a minimum. There is, however, a very wide dif-

TABLE XVII. TRANSFORMER OVERHEAD CHARGES WHEN RURAL DISTRICTS ARE SERVED FROM ISOLATED TRANSFORMERS

13,200-Volt Line

Cost of 5-kw. transformer installed, including high-tension fuses and horn-gap arrester	$125.00
Interest, repairs and depreciation, 20%	25.00
Core loss, 91 watts or 800 kw-hr. per annum at 2 cts.	16.00
Labor for trouble calls	9.00
Total extra cost of service per annum	$ 50.00
Total extra cost of service per month	4.16
Cost of 3-kw. transformer, installed, including high-tension fuses and horn-gap arresters	$100.00
Interest, repairs and depreciation, 20%	$ 20.00
Core loss, 53.5 watts or 470 kw-hr. per annum at 2 cts.	9.40
Labor for trouble calls	8.60
Total extra cost of service per annum	$ 38.00
Total extra cost of service per month	3.16

2200-Volt Line Extended from City Limits

Cost of 1-kw. transformer, installed	$ 30.00
Interest, repairs and depreciation	6.00
Core loss, 20 watts or 175 kw-hr. per annum at 2 cts.	3.50
Labor for trouble calls and service	3.50
Total extra cost of service per annum	$ 13.00
Total extra cost of service per month	1.08
Cost of 3-kw. transformer	$ 45.00
Interest, repairs and depreciation	9.00
Core loss, 35 watts or 307 kw-hr. per annum at 2 cts.	6.14
Labor for trouble and service	3.50
Total extra cost of service per annum	$ 18.64
Total extra cost of service per month	1.55
Cost of 5-kw. transformer	$ 60.00
Interest, repairs and depreciation, 20 per cent	12.00
Core loss, 45.5 watts or 400 kw-hr. per annum at 2 cts.	8.00
Labor for trouble and service	3.50
Total extra cost of service per annum	$ 23.50
Total extra cost of service per month	1.96

ference between the depreciation on copper wire and on transformers. Wire depreciates very slowly and has a high fixed salvage value. Transformers have an uncertain life and their scrap value is low. Taking these conditions into consideration, it is good practice to spend considerably more on bus copper than is actually required to strike an economical balance. An excess copper investment equal to 50% of the transformer cost is not too much to allow.

As an example, take two secondary bus sections, each fed by 5-kva. transformers, the investment on which, in position, will be about $150. By connecting these bus lines and substituting a 10-kva. transformer, advantage is taken of the diversity on the bus, thereby permitting the connecting of more load. The new transformer investment will not exceed $95, showing a saving of $55

that can be spent for connecting and increasing the size of the secondary bus and still maintain a balance as regards investment. Assuming interest at 6% and depreciation at 7.5%, the annual charges will be $20.25 and $12.82 respectively, showing an annual saving of $7.43 by using one unit in place of the two. Now, if interest is assumed at 6% and depreciation at 2.5% on copper wire, and this saving is capitalized, it will be possible to spend $87 plus the $55, or $142, on the secondary bus and still maintain an economical balance. This makes no allowance for the saving due to lower core loss with the single unit as compared with two smaller units. If this were taken into consideration, a still greater secondary investment could be justified. In purchasing transformers it is very poor policy to stock the small units. A 5-kva. unit is small enough to use regularly on any system of distribution.

As regards ratios and taps for distribution transformers, 2300-volt primary and 115-230-volt secondary windings without taps give the best all-around results. These will operate over a primary range of 2200 to 2400 volts. Taps have no real advantage and introduce complication in the end turns where the greatest strength is required. The double primary winding used in earlier days is of no use at present, and its omission together with that of taps makes possible the elimination of the primary terminal board which has been the cause of so many transformer failures.

Factors that Determine Economical Life of Transformers. In Electrical World, Jan. 13, 1917, Theodore B. Morgan gives the following considerations involved in an investigation to ascertain whether it is economical to continue in service, hold in reserve or condemn and junk long-used transformers. Unless steps are taken occasionally to weed out inefficient or antiquated transformers from distribution systems certain units will be found which have become uneconomical to operate as compared with newer designs. This is especially true of "old timers," since as a rule they age more rapidly than modern types. According to manufacturers' statements and judging from results of tests to force aging, recently designed transformers do not age appreciably. It is doubtful, therefore, whether future developments in this apparatus will permit sufficient reduction in losses to justify the replacement of modern units for this reason alone. It should be emphasized, however, that only future experience can prove this contention.

To determine whether it is economical to continue in service, hold in reserve, or condemn and junk transformers which have been in service several years the writer has conducted extensive investigations, part of the results of which are presented in what follows. In arriving at conclusions it was considered advisable to take the following conditions into account: (1) Unit cost of energy at the switchboard; (2) number of hours per day normal and maximum load is liable to last; (3) relation of transformer rating to connected load; (4) iron loss; (5) copper loss; (6) kva. drawn from feeder by transformer for exciting at no load; (7) cost of new transformer to replace one in service; (8) size of wire and load carried by feeder giving service; (9) distance of transformer from

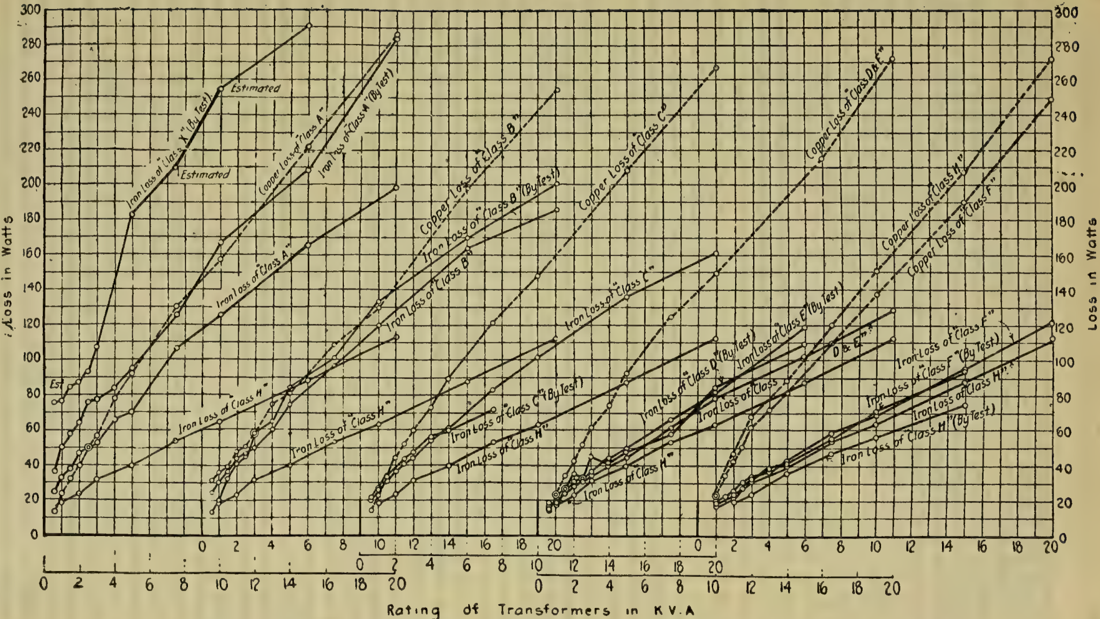


Fig. 6. Comparisons of transformer losses at time of manufacture and after operation.

station; (10) power factor of feeder load; (11) profit that can be realized by central station by change; (12) service characteristics; (13) better regulation given to secondary distribution system.

Data included under the first item were readily obtained from the company's operating accounts, while information on items 2 and 3 was secured by making tests in typical districts and by comparing the ratings of transformers in service with statistics secured from the commercial department. Tests on thirty-odd transformers rated at 0.6 to 5 kva., and which had been in service for different periods up to 17 years, were made to secure data for items 4 and 5, these being facilitated by the replacement of the units shortly before the tests by transformers of large rating.

These tests as well as all subsequent ones were conducted to show the losses under operating conditions, voltage being applied to the low-tension coils of the transformer at the rating given by the manufacturer. No attempt was made to insure pure sinusoidal waves. On the other hand, it was most desirable to have the wave formation identical with that supplied to the system under operating conditions, otherwise the tests would have been valueless or would have given erroneous results when applied to distribution problems later on.

Preliminary tests were made to determine what apparent changes might be expected under varying conditions. When generators producing different wave forms were paralleled on the system the difference in loss was apparent, but to such a small degree that it was not appreciable. Operation of generators on two other systems caused a greater variance, but at no time greater than 2%.

Other tests made to determine the variation in loss when the rated voltage was impressed upon the transformers with and without additional external variable resistances indicated that when a lamp bank or meter-testing rheostat was used the error introduced by the change of voltage wave was not sufficient to be more than discernible by the tester.

When the iron and copper loss data had been tabulated, however, the results for transformers of the same rating varied so greatly that it was hopeless to attempt any conclusions without securing information that would permit classification of the data. Consequently, manufacturers were asked for the history of transformer design and for such data as would be used to classify the transformers into groups, each group to represent a distinct departure from the preceding group as regards iron and copper losses. Lists of these losses were also secured. From this information all of the 900 transformers tested to date and having ratings from 0.6 kva. to 600 kva. were classified as shown in Table XVIII:

With this classification as a guide, cards were selected from the transformer files for 4 transformers of each size in each class. By routing a regular testing crew according to these cards it was possible to make a large number of tests with the least amount of travel, 118 tests being made in one district. The exciting currents were determined at the same time for item 6. Since some of the transformers of each class were miles apart, or could not be

TABLE XVIII. CLASSIFICATION OF TRANSFORMERS *

Class X — Designed for 133-cycle, 1040/2080-volt primary, 54/108-volt secondary, about 19 years old.
Class A — Designed for 60-cycle, 1040/2080 volt primary, 54/108 or 108/216-volt secondary, 19 to 11 years old.
Class B — Designed for 60-cycle, 1040/2080-volt primary, 54/108 or 108/216-volt secondary, 11 to 9 years old.
Class C — Designed for 60-cycle, 1100/2200-volt primary, 110/220-volt secondary, 9 to 6 years old.
Class D — Designed for 60-cycle, 1100/2200-volt primary, 110/220-volt secondary, 6 to 5 years old.
Class E — Designed for 60-cycle 2200-volt primary, 110/220-volt secondary, 5 to 4 years old.
Class F — Designed for 60-cycle, 2200-volt primary, 110/220-volt secondary, 4 to 1 years old.
Class H — Designed for 60-cycle, 220-volt primary, 110/220-volt secondary, less than 1 year old.

* All transformers operating on 60-cycle, 2200-volt, with 110 and 220-volt, two and three-wire secondaries.

disconnected for testing, and as certain sizes of some classes were rare or were not in use at all, it was impracticable to carry out the initial intention of testing four transformers of each size. However, enough tests were made so that data were secured for about 23% of the total number of units installed, the smallest percentage of any class being about 18% for Class E. Where data could not be secured for certain sizes of any class, where the data were insufficient for making satisfactory averages, or where the tests were not as accurately conducted as desired the losses were estimated.

While test data were secured under operating conditions for transformers rated as high as 600 kva., only that for sizes (up to 20 kva.) which are most common on all systems have been plotted, since it is by the proper selection of these units that the largest saving can be made. The curves are based on the average losses as found by over 500 tests made during a period of four years, and are shown in Fig. 6, with curves plotted from the data furnished by manufacturers on losses at the time of manufacture. The manufacturers also gave data on what the losses should be at the time of test, but the values were much below those actually measured, due probably to differences which exist between theoretical and actual conditions. For instance, wave form in commercial may not and is usually not sinusoidal, the transformer may be overloaded in kilovolt-amperes but not in kilowatts, and the oil used for heat radiating purposes may be lacking or not in the proper operating conditions, thus permitting the iron cores to age.

While Class X and some of Class A transformers were operated for a time without oil as a heat-radiating medium, this condition was corrected in 1902–1903. The oil in many of the older types had reduced from one-third to two-thirds of its original bulk, thereby becoming thick and sluggish. Several cases were found where the oil and insulating compound had combined into a thick, sticky mass covering part of the laminations and coils. These

conditions were taken into consideration after making the tests on the transformers, it being decided that the iron loss had not been affected except where excessive load in comparison to the radiating capacity had been carried. The averages of test results can therefore be used only as a guide for transformers of the class tested, as the losses of each individual transformer are liable to change. For estimating purposes, however, the curves will be found fairly accurate. It may be pointed out that for the period of transformer development represented, the iron losses of similar size units have been gradually reduced and the ratio of copper

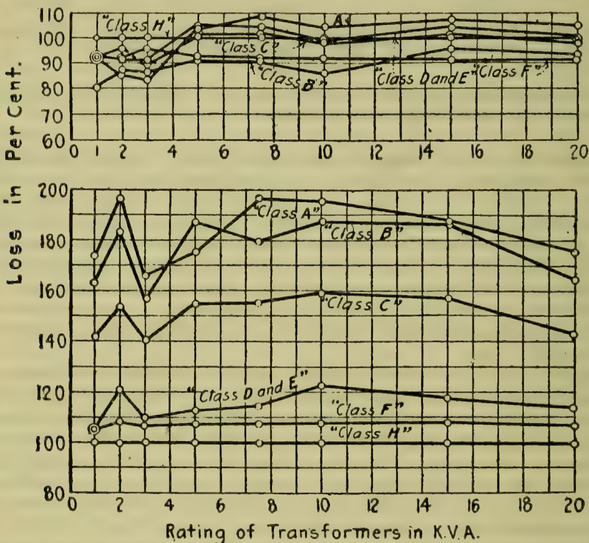


Fig. 7

loss to iron loss gradually increased from 1:1 to about 2:1, thus permitting a higher all-day efficiency when the load factor is low. Figs. 7 and 8 compare the iron and copper losses of modern transformers with those of older types in percentages.

From the manufacturers' list prices and discounts for different size units figures (Table XIX) were obtained on which to base the cost of replacing transformers. The cost to set transformers on lines includes freight, cartage, etc., and is an average for removing and setting a number of transformers when arrangements have been made to carry on the work systematically. The junk values are based on prices that have been paid in the past for good transformers with high iron loss. These figures are necessarily

TABLE XIX. ULTIMATE COST OF NEW TRANSFORMERS ASSUMED FOR ESTIMATING PURPOSES

Size of transformers in kva.	Cost at factory	Cost set on lines	Junk value of old transformers	Ultimate cost of new transformers on lines
1	23.00	26.00	3.00	23.00
1.5	27.00	30.00	4.00	26.00
2	32.00	35.00	5.00	30.00
2.5	36.00	39.00	6.00	33.00
3	40 00	43.00	7.00	36.00
4	47.00	50.00	9.00	41.00
5	56.00	59.00	10.00	49.00
7.5	73.00	76.00	14.00	62.00
10	89.00	92.00	18.00	74.00
15	118.00	121.00	25.00	96.00
20	145.00	148.00	30.00	118.00

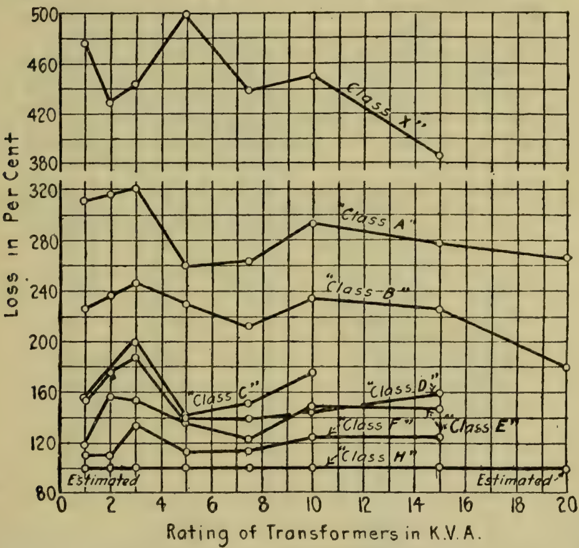


Fig. 8. Comparisons of the iron and copper losses of transformers

All of the curves are plotted with the assumption that the losses of class H transformers are 100 per cent. The curves of Fig. 7 are based on the average losses at time of manufacture while those of Fig. 8 are based an actual test data. The upper curve of Fig. 7 represents copper losses and lower one iron losses. Fig. 8 also represents iron losses.

arbitrary, as it is impossible to arrive at true costs for a great number of points where freight, cartage and labor conditions differ from those assumed. From these data and the assumption that

energy at the switchboard cost 1 ct. per kw.-h., curves slanting upward to the right in Fig. 9 were plotted. On account of the different methods used in computing depreciation and the fact that many companies set aside a reserve fund rather than figure

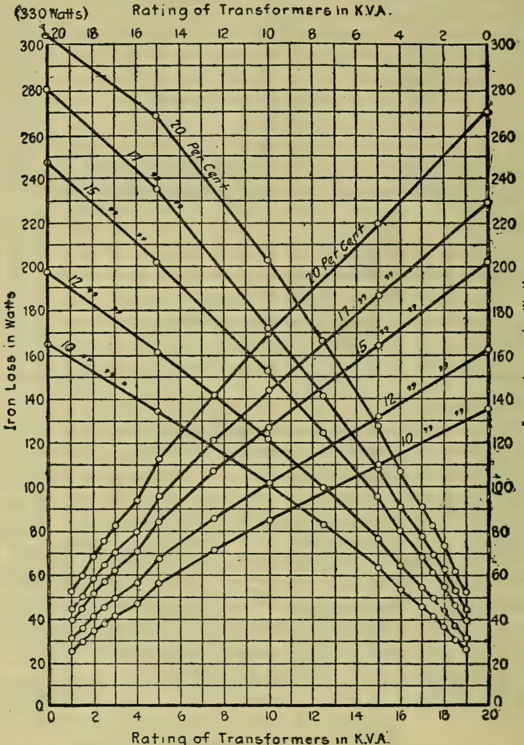


Fig. 9. Return on investment which can be realized by substituting new transformer for one having certain iron loss

The curves sloping upward to the right are based on the values given in the right-hand column of Table II, while those sloping to the left are based on the figures in the second column of the table. An energy cost of 1 cent per kilowatt-hour is assumed.

depreciation on small items, depreciation is not considered, although it may readily be introduced and results worked up for individual cases with the figures and curves given. A comparison of the curves of Fig. 9 with those of Fig. 6 shows that the substitution of a modern type transformer for a class X transformer will pay 20%

on the investment, while the replacement of Classes A, B, C, etc., will permit gradually smaller returns. The curves in Fig. 9 which slope upward to the left show smaller returns from the substitution of modern transformers, since they are based only on the cost of the new transformers and not on the replacement cost.

Additional advantages are often secured by changing transformers, such as increasing the feeder rating, improving power factor and regulation, since two or more transformers can often be replaced by one and the conductor combined to serve as one circuit.

When the iron loss of transformers is relatively high and the consumer's consumption small the cost of energizing the units will sometimes exceed the actual income received. Such a case was found where a 5-kva. transformer of the X class was serving a single customer whose bill never exceeded the minimum charge of 50 cents per month except one month of the year. The income was $9 a year while the cost of service, including $7 interest and fixed charges and $17.50 for energy consumed by the transformer, made a total yearly cost of $24.50 without charges for consumer's energy, bookkeeping, meter reading, billing and the like. With an iron loss of 180 watts the power factor was 20% at no load. Since 900 kva. was supplied to the transformer the greater part of each

TABLE XX. COST OF SETTING TRANSFORMERS AND VALUE OF THOSE REMOVED FROM CONNECTICUT SYSTEM

Kva.	Transformers set	Cost of transformers set (Table XIX)	Transformers removed	Value of transformers removed if purchased at this time (Table XIX)	Transformers removed from lines in excess of those set of same size	Value of excess transformers if purchased new
.6	1	$23.00	6	$138.00	5	$115.00
1	2	46.00	12	276.00	10	230.00
1.5	4	108.00	9	243.00	5	135.00
2	..	.....	5	160.00	5	160 00
2.5	3	108.00	6	216.00	3	108.00
3	3	120.00	7	280.00	4	160.00
4	..	.....	4	188.00	4	188.00
5	4	224.00	7	392.00	3	168.00
7.5	8	584.00	10	730.00	2	146.00
10	1	89.00	1	89.00	..	.....
15	2	236.00	5	590.00	3	348.00
20	..	.....	3	435.00	3	435.00
25	..	.....	3	576.00	3	576.00
30	1	219.00	..	.....	..	.....
40	1	270.00	..	.....	..	.....
Total	30	$2027.00	78	$4313 00	50	$2769.00

day the line loss was way out of proportion to the energy sold and the rating of a 9-mile section feeder was considerably reduced.

While all central stations endeavor to keep their distribution systems from becoming loaded with networks of wire or over-rated transformers, points can invariably be found where there is too much wire and too little transformer capacity or too much capacity for the size of the installation. Such conditions cause a loss to the

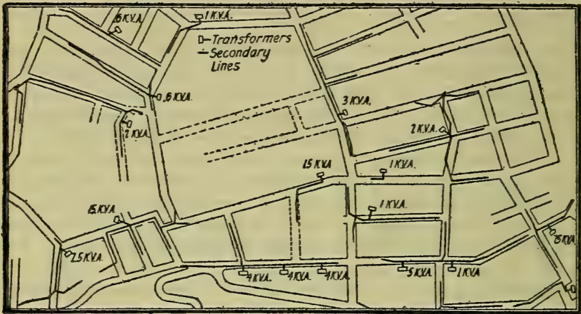


Fig. 10

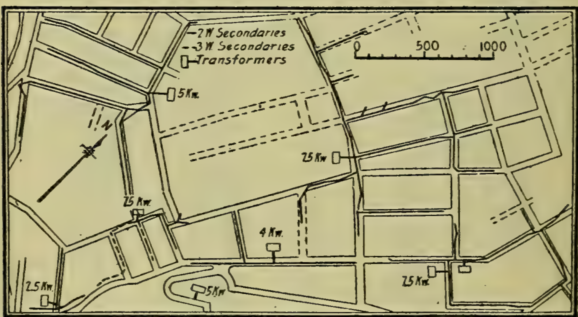


Fig. 11

Figs. 10 and 11. Portion of distribution system before and after rearrangement

operating company, and unless careful supervision is maintained in making extensions or installing transformers, thousands of dollars may be uneconomically strung in the air instead of being used to better advantage elsewhere.

In working on secondary distribution systems, it has been found that iron losses are often rated far below the actual figures. For

instance, an excitation current of 0.5% to 10% of the unaccounted for current, as sometimes claimed, is entirely too low. Tests show that a system furnishing 24-hour service must be in perfect condition to show a loss as low as 20%, while for sparsely populated residential districts the loss is seldom as low as 40%. Analyzation of the unaccounted-for current in a number of systems indicates that the distribution transformers take up anywhere from 38 to 60%, estimators usually overlooking the fact that iron loss is continuous for the 24 hours in the day and for 365 days in the year. Another item which is usually overlooked is that old transformers have the greater losses and should be considered separate from the more modern types, which have very low losses by comparison.

As an example of a case where the foregoing considerations were taken into account in rearranging a distribution system the accompanying maps and data of Table XX are presented. The map in Fig 10 shows distribution conditions in a section of a Connecticut town before changes were made and where the system had grown with the demand for service.

In rearranging the system 78 of 141 transformers were removed and 30 hung on the lines, making 93 transformers with a total rating of 1487 kva. instead of 141 with a total rating of 1709 kva. About the only transformers purchased for the change were a 30-kva. unit and a 40-kva. unit, since a sufficient number of various sizes were secured by rearranging to fit in places where transformers were needed. In general the secondaries were not run more than 9 sections from their corresponding transformer. When it was possible to form loops, however, 20 to 25 section secondaries could be employed on fairly heavily loaded circuits.

TABLE XXI. SAVING DUE TO REMODELING OF CONNECTICUT DISTRIBUTION SYSTEM

Transformers removed from lines	78
Kva. capacity	421.1
Value if purchased new	$4,313.00
Transformers set on lines	30
Kva. capacity	199.1
Value if purchased new	$2,027.00
Saving in kw-hr. per year in reduced iron loss	36,667
Valued at 1 ct. per kw-hr.	$366.67
* Added rating of 11,000-volt feeder in kva.	20.50
Pounds of base wire removed, 2313 (junk), valued at	$578.25
Pounds of weather-proof wire run, 2150, valued at	$602.00

* Due to increasing power factor of exciting current.

In addition to other wire removed and run as noted elsewhere about 6000 ft. of No. 6 new weatherproof wire, which cost 30 cts. a pound, was removed and substituted by copper-clad wire equivalent to No. 10 copper that cost 15 cts. a pound two years before. This substitution was permitted by making one long run with a 1-kva. transformer at the end, the copper-clad wire being obtained from a suburban line where the increased load had demanded a change to a larger size of conductor.

For the benefit of companies contemplating changes similar to those outlined, attention is called to a few of the many difficulties encountered. For instance, after the primary and secondary system have been mapped and comprehensive tests made on the feeders, transformers and secondary system, the value of the results may be entirely lost because infrequent loads have not been taken into consideration. If some evasive load of this nature crops up it may be necessary to change conductors and transformers, making the expense about double the initial or estimated expense. Such occurrences can often be avoided, however, by conferences with the line superintendents and foremen, who are usually acquainted with the characters of the loads. Better teamwork will usually be obtained, too, if their confidence is secured, since they do not generally take kindly to reconstruction of work which they have spent time and money to perfect. Another point to recognize is that the good will or enmity of the community will be secured depending on whether the rehabilitation is attended with improved or unsatisfactory results. Under no consideration should anyone undertake extensive readjustments unless he has a knowledge of local conditions, good engineering training, practical experience, and testing and mapping facilities.

Costs per Kilowatt of Steam Power Electric Plants. The costs in Table XXII are from appraisals by the authors made in 1911 and 1912 on the Pacific Coast. "Base costs" only are given, the table including no charges for engineering, business management, legal and general expense, interest during construction or brokerage.

Electric Power Plant Cost. (Condensed by Lefax from an article by M. C. McNeil in Electric Journal, March, 1914.) The cost of construction or installation of steam turbine driven electric power plants, complete from real estate up to and including all auxiliary apparatus, for a given size of plant, is fairly constant throughout the country. Local conditions may, however, cause an appreciable variation from the average case. The size of plant affects the cost very materially, and the unit cost tends to increase rapidly for small plants, and decrease less rapidly for large plants.

The installation cost of plant affects the cost of power produced in that the fixed charges are a part of the operation cost, say 10.5% for turbine plants, made up of interest 5%, taxes and insurance 2%, and amortization fund 3.5%, the latter being sufficient at 4% compound interest to replace the plant in 20 years. The total cost of power, consisting of operating costs and fixed charges, is a fluctuating quantity, depending upon size of plant and load-factor. The principal variation however is due to operating expense, which constitutes about 80% of the total power cost, and is made up of the following items:

Fuel. Coal is rarely less than 50%, and sometimes as high as 80% of the total operating expense. The larger the plant and the greater the load-factor, the better the fuel economy. Load-factor equals ratio of average load during any period, as 24 hrs., to the average maximum load for one hour during that period. As the

TABLE XXII. COSTS PER KILOWATT OF STEAM POWER ELECTRIC PLANTS

Rated capacity	13,000 kw. cost per kw.	3,200 kw. cost per kw.	2,500 kw. cost per kw.	1,750 kw. cost per kw.	1,200 kw. cost per kw.
Buildings	$12.72	$50.20	$16.00	$15.52	$32.61
Stacks	2.41	3.58	.93	2.25	3.94
Machinery foundations	2.62	2.53	4.58	1.47	2.21
Boilers, heaters, economizers, etc.	10.96	38.93	9.28	17.41	48.73
Piping	5.29	26.67	7.87	1.90	7.10
Pumps	.54	8.39	.60	.57	1.36
Reciprocating engines	....	47.18	4.12	16.78	....
Generators	....	20.00	3.82	16.37	20.56
Condensers	....	....	....	3.75	....
Turbo generators	22.00	....	14.94	21.40	6.61
Exciters	.75	.78	.59	....	1.24
Switchboards, instruments and wiring	2.87	2.03	1.44	2.90	2.96
Cranes	.58	2.35	....	1.11	2.01
Miscellaneons	2.79	4.49	3.01	.63	9.66
Total power plant, buildings and equipment	$63.53	$207.13	$67.18	$102.06	$138.99
Real estate	....	....	....	....	56.23
Sub-station equipment	....	....	....	....	....
Other property	....	....	....	....	....
Grand total	....	....	$73.18	....	$195.22
Horsepower of boilers	8,760	4,000	1,517	1,084	2,400
Working pressure, lb.	....	180	150 and 180	....	240 and 140
Cost of boilers, etc., per hp.	$16.28	$31.13	$15.28	$28.10	$24.35
Cost of piping per boiler, hp.	7.85	21.32	12.95	3.07	3.56
Cost of pumps per boiler, hp.	.88	6.72	1.00	.92	.68
Hp. of boilers per kw. of generators	0.67	1.25	0.61	0.62	2.00

load-factor falls off the fuel cost increases, due to increased steam consumption per kw.-hr. produced. The general plant losses and inefficiencies are proportionately greater the smaller the plant, and the lesser the load-factor.

Labor Costs follow the same general trend as fuel costs, although not so fluctuating. The load-factor does not affect the labor as much as it does the fuel item, as practically the same labor will be required for a plant having a 75% load-factor as for one having a 50% load-factor, if the maximum load for the two plants is the same.

Supplies. The items oil, waste and supplies, and repairs and maintenance are indeterminate quantities, although experience has shown that they bear an approximate relation to labor and fixed charges; oil, waste and supplies being around 20% of the labor cost, and repairs and maintenance about 15% of the fixed charges.

TABLE XXIII. COST OF INSTALLATION PER KW. STEAM TURBINE DRIVEN

	Size of plants — kilowatts					
	500	1000	2000	3000	4000	5000
Building, real estate and excavating	16.75	14.50	13.25	12.00	11.00	10.00
Turbines and generators	32.60	25.75	21.15	17.30	15.80	15.00
Condensers	10.60	6.75	4.50	3.90	3.50	3.00
Boilers, stokers, superheaters and stacks	32.65	28.50	25.50	23.60	21.50	20.00
Bunkers and conveyors	5.50	5.00	4.50	4.00	3.50	3.25
Boiler feed and service pumps	1.25	1.25	1.00	0.75	0.50	0.50
Feed water heaters	2.00	1.75	1.50	1.25	1.00	0.80
Switchboard and wiring	3.50	3.25	3.25	3.00	2.75	2.75
Exciters	4.00	3.00	2.00	1.50	1.00	0.75
Foundation (machinery)	1.25	1.25	1.00	1.00	0.75	0.75
Piping and conduits	5.75	5.75	6.00	6.00	6.25	6.25
Crane	1.75	1.75	1.50	1.25	1.00	0.75
Supt. and engineering, etc.	6.50	5.00	4.25	3.75	3.25	3.00
Total	124.10	103.50	89.40	79.30	71.80	66.80

Each of the plants considered in Table XXIII is normal rated at the size given; that is, the 500 kw. plant has 3 200-kw. normal rated units, making it possible to operate the plant with 2 turbines running, the third unit being used only during the peak load period. However, if 1 unit is shut down for repairs, the peak load can be handled by the remaining 2 machines, although at reduced economy. Ample capacity is provided, such as spare boiler, extra boiler feed and service pumps and other extra apparatus consistent with good design.

Labor saving apparatus is not warranted for the smaller plants. The 1000 kw. plant is about the dividing line, above which it is economy to install labor saving machinery.

Table XXIV gives the cost of power generation in cents per kw.-hr. for steam turbine generating units. Cost of fuel was calculated for $3.00 coal. For simplicity, the steam operating conditions of all the plants were considered the same, being 175 lbs. steam pressure,

100 deg. superheat and 28 in. vacuum. These conditions may be rather high for the smaller units, but there would not be any great difference in total power costs if the steam pressure was lowered and superheat omitted, as saving in fuel due to the more economical operating conditions just about balances the extra fixed charges.

TABLE XXIV. COST OF POWER GENERATING — TURBINE DRIVEN

Cost in cents per kilowatt-hour

Size of plant, kws.	Fuel	Labor	Oil, waste and supplies	Repairs and maintenance	Operating costs	Fixed charges	Total
			100% Load-Factor				
500	0.449	0.132	0.026	0.025	0.632	0.148	0.780
1000	0.364	0.094	0.019	0.021	0.498	0.124	0.622
2000	0.328	0.073	0.015	0.018	0.434	0.107	0.541
3000	0.304	0.065	0.013	0.016	0.398	0.095	0.493
4000	0.289	0.058	0.011	0.014	0.372	0.086	0.458
5000	0.271	0.053	0.010	0.013	0.347	0.080	0.428
			75% Load-Factor				
500	0.548	0.166	0.033	0.031	0.778	0.197	0.973
1000	0.428	0.116	0.023	0.026	0.593	0.165	0.758
2000	0.389	0.088	0.019	0.021	0.517	0.143	0.660
3000	0.352	0.079	0.016	0.019	0.466	0.127	0.593
4000	0.327	0.072	0.014	0.017	0.430	0.115	0.545
5000	0.308	0.065	0.013	0.016	0.402	0.107	0.509
			50% Load-Factor				
500	0.741	0.236	0.047	0.042	1.066	0.296	1.362
1000	0.558	0.166	0.033	0.035	0.792	0.248	1.040
2000	0.494	0.118	0.024	0.030	0.666	0.214	0.880
3000	0.438	0.106	0.021	0.027	0.592	0.190	0.782
4000	0.402	0.097	0.019	0.024	0.542	0.172	0.714
5000	0.380	0.088	0.017	0.022	0.507	0.160	0.667

In central station service the ideal condition of 100% load-factor is never reached and seldom approached, the condition of 75% load-factor being considered very good, and only attained in some instances.

Prime Movers Other Than the Turbine. The comparison is made on the basis of 1,000 kws. normal capacity plant, all conditions being similar, and the gas engine being supplied with fuel from a producer gas plant.

COST OF INSTALLATION 1,000 KW. PLANT

	Per kilowatt
Turbine	$103.50
Reciprocating steam engine	132.50
Comb. recip. engine and turbine	127.00
Gas engine	162.50

Table XXV gives cost of producing power for the different plants. For plants of other sizes than 1,000 kws. the same proportional differences between plants of various sizes as shown in Table XXIII can be used and will be approximately correct.

TABLE XXV. COST OF POWER GENERATION PER KW-HR. 1,000 KW. PLANT

	Fuel	Labor	Oil, waste and supplies	Repairs and maintenance	Operating cost	Fixed charges	Total
			100% Load-Factor				
Turbine	0.364	0.094	0.019	0.021	0.498	0.124	0.622
Recip. steam engine	0.390	0.105	0.023	0.024	0.542	0.166	0.708
Comb. recip. and turbine	0.340	0.110	0.025	0.025	0.500	0.158	0.658
Gas engine	0.260	0.165	0.033	0.035	0.493	0.213	0.706
			75% Load-Factor				
Turbine	0.428	0.116	0.023	0.026	0.593	0.165	0.758
Recip. steam engine	0.461	0.128	0.028	0.030	0.647	0.222	0.869
Comb. recip. and Turbine	0.404	0.134	0.030	0.032	0.600	0.211	0.811
Gas engine	0.334	0.195	0.039	0.044	0.612	0.285	0.897
			50% Load-Factor				
Turbine	0.558	0.166	0.033	0.035	0.792	0.248	1.040
Recip. steam engine	0.602	0.182	0.039	0.040	0.863	0.332	1.195
Comb. recip. and turbine	0.527	0.189	0.042	0.043	0.801	0.316	1.117
Gas engine	0.482	0.252	0.052	0.055	0.841	0.426	1.267

The turbine economy, however, is proportionately better for larger units than is either the gas engine or reciprocating steam engine, though the reverse is true to some extent with smaller plants.

Costs of Steam Turbo-Electric Central Stations. O. S. Lyford, Jr., and R. W. Stovel, in Electric Journal, April, 1912, give the following high and low costs of steam turbo-electric generating stations of 2,000 to 20,000 kw. capacity, based on maximum continuous capacity of generators at 50 deg. C. rise.

	Dollars per kw. High	Low
Preparing site: Clearing structures from site, constructing roads, tracks, etc.	$ 0.25	....
Yard work: Flumes for condensing water, siding, grading, fencing, sidewalks, etc.	2.50	$1.00
Foundations: Foundations for building, stacks and machinery, excavation, piling, waterproofing, etc	6.00	1.00
Building: Frame, walls, floors, roofs, windows, doors, coal bunker, etc., exclusive of foundations, heating, plumbing and lighting	12.00	4.00
Boiler room equipment: Boilers, stokers, flues, stacks, feed pumps, feed water heater, economizers, mechanical draft, piping and covering, except condenser water piping	24.00	12.00
Turbine room equipment: Steam turbines and generators, condensers, condenser auxiliaries, condenser water piping, oiling system, etc.	22.00	12.00
Electrical switching equipment: Exciters, masonry switch structure, switchboards, switches, instruments, etc., all wiring except for lighting	5.00	2.00
Service equipment: Cranes, lighting, heating, plumbing, fire protection, compressed air, furniture, permanent tools, coal and ash handling ma-		

	Dollars per kw. High	Low
chinery, etc.	$ 5.00	$ 2.50
Starting Up: Labor, fuel and supplies for getting plant ready to carry useful load	1.00	0.50
General Charges: Engineering, purchasing, supervision, clerical work, construction plant and supplies, watchmen, cleaning up, etc.	6.00	3.00
Total cost of plant, except land and interest during construction	$83.75	$38.00

Construction Costs of Power Houses. A. E. Dixon gives the following data in Power, October 3, 1911.

8000-KW. PLANT OF THE WEST JERSEY & SEASHORE RAILROAD, AT WESTVILLE, N. J.

(B. F. Wood's paper before the American Institute of Electrical Engineers).

Building, stacks, coal and ash-handling machinery	$354,000
Equipment	640,000
Total	$994,000
Total cost per kw.	$110

8500-KW. PLANT OF THE FORT WAYNE & WABASH VALLEY TRACTION COMPANY, AT SPY RUN, FORT WAYNE, IND.

(Paper before American Street and Interurban Railway Engineers' Association, by J. R. Bibbins).

	Cost per kw.
Building, including general concrete and steel work, galleries, coal bunker, smoke flue, condenser pit, coal-storage pit, etc.	$10.97
Generating plant, including turbines, generators, exciters, cables, switchboards, transformers and ventilating ducts	30.55
Boiler plant, including boilers, superheaters, stokers, piping, pumps, heaters, setting, breechings and tanks	13.92
Condenser plant, including condensers, pumps, piping, free exhausts, water tunnels and intake screen	3.98
Coal-handling plant, including crane, crushers, motor and track	0.94
Erection, superintendence, engineering and miscellaneous	5.49
Total, excluding land and railroad siding	$66.30

3000-KW. PLANT OF THE YOUNGSTOWN & OHIO RIVER RAILROAD AT WEST POINT, OHIO

(C. W. Ricker's addendum to paper by J. R. Bibbins before the American Institute of Electrical Engineers, July, 1908)

	Cost per kw.
Building and fixtures: foundation, general excavation, concrete work, including condenser wells, overflow, ash tunnel, steel frame and building superstructure, ash-handling apparatus, coal trestle, chimney, smoke flue and crane	$21.40
Boiler plant: 6 400-hp. water-tube boilers, settings, furnaces, pumps, heater, piping and covering	14.24

	Cost per kw.
Generating plant: 3 1000-kw. 3-phase, 25-cycle, 400-volt, turbo-generators, 6 375-kw. 22,000-volt, step-up transformers, duplicate exciters, switching and protective apparatus	$37.59
Condenser plant: 3 barometric condensers with centrifugal pumps, water intake and dam, including the deepening of the channel	6.41
General expense: including the expenditures which could not be distributed easily and part of the expense of supervision	2.42
Complete	$82.06
Substation equipment in power house; 2 300-kw. synchronous converters with 5-panel switchboard	4.20
Total	$86.26

	30,000-kw. plant	10,000-kw. plant
Excavation and foundations, including condenser intake and outflow	$ 8.97	$ 4.89
Superstructure and steelwork	19.04	3.57
Turbo-generators and condensers	26.13	24.83
Boilers, stokers, chimneys and flues	11.11	15.75
Coal- and ash-handling equipment	1.62	1.40
Boiler-feed pumps, heaters, etc.	0.52	2.80
Piping and valves	3.17	6.58
Exciters, etc.	1.01	....
Crane, air compressor, etc.	0.33	0.67
Switching equipment	6.02	1.24
Water supply	0.83	0.38
Engineering	3.90	....
Total cost per kw.	$82.65	$62.11

In Koester's "Steam-Electric Power Plants" the following are given:

	Cost per kw.
Boston Edison, L street plant	$125.00
Interborough, Fifty-ninth street plant, New York City	150.00
Superstructure of latter plant only	32.00

The cost of foundations will vary greatly and is one of the elements which local conditions affect to a greater degree than most others. The conditions vary from liquid mud to solid rock. Rock may be desirable owing to its high bearing value, but it is very expensive to excavate and the depth of excavation is frequently fixed by the local water level. The cost of the foundations will vary from 2 to 12% of the total cost per kw. of generating capacity. The lower costs hold where firm sand or some other readily excavated material with a high bearing value is found upon the site and the water level does not fluctuate very much. The higher costs will be found with rock excavation where the character of the rock is such that it breaks out very roughly and leaves a large excess of the excavation to be refilled with concrete. Similar high costs will be found where the underlying strata are such as to involve the

use of long piles and a heavy concrete mat built within a cofferdam. In some localities it is possible to use a concrete raft, and by keeping the bearing pressures down the structure can be floated upon the soil. A raft of this kind must be so designed that it will distribute the pressure, and this calls for the use of reinforced concrete and careful proportioning to carry the heavy local loads.

Steel framing must be so proportioned as to carry the loads, and these will vary greatly. In many plants double, and in one case three decks of boilers are used, and if a heavy bunker must be supported, the steel framing will be proportionately heavy. The length of the span between columns in the boiler room will be fixed by the size of the boilers, and it is advisable to keep the column spacing below 20 ft. This spacing, or a little less, will accommodate nearly all types of boiler. Where longer spans are used the heavy girders increase the cost. The minimum amount of steel will be required when the roof trusses are supported upon the walls and carry the roof alone. This construction is objectionable as the steel work must be held back to suit the masonry and the masonry will then be delayed while the steel is being placed. This procedure will generally cost more than when the steel is so arranged that it can be erected entirely independent of the walls. The independent steel skeleton also permits the use of thin curtain walls, which results in a saving in masonry as well as in the cost of erection.

Double-deck power plant, with the boiler room at the bottom and the operating floor above, seems designed to get the maximum amount of power concentrated in a possible minimum floor space. This type of plant is an inversion of the original double-deck plant in which the boiler room was located above the operating floor, as at that time this type of construction was adopted to suit reciprocating engines owing to the difficulty 25 years ago of handling the heavy engine parts and erecting them on the second floor.

One of the objections made to the double-deck plant and the plant with a heavy overhead bunker has been the use of columns passing up through the walls of the boiler settings. In one or two cases water cooling has been employer for the columns placed in the division wall between the 2 boilers of a battery, owing to the fear that these columns might expand unduly and irregularly from alternate cooling and heating. The coefficient of linear expansion of steel or iron is about 0.000006 per deg. F.; hence if such columns became heated to a temperature 300 deg. higher than the atmosphere they would expand 0.001800 part of their length. With a column 35 ft. high, this would amount to about .75 in. and might be very serious.

Cost of boilers and stokers ranges from 10 to 15% of the total. Brick settings may or may not be tight at the start, but they are rarely permanently tight, and this leakage is by no means unimportant. Internally fired boilers or marine settings will entirely prevent leakage into or out from the setting. Why they are not used more extensively it is difficult to say.

Engine-driven units cost more than turbo-generators, but the type

of unit to be selected will depend upon local conditions. When a liberal supply of cooling water can be secured for the cost of pumping it is possible to maintain a high vacuum, and the turbine may be the most economical prime mover. Where cooling water is scanty and a high vacuum cannot be maintained, the reciprocating engine has many points in its favor. The turbine is inherently a high-speed proposition and is better suited to the driving of alternating-current generators than it is to driving a direct-current generator. High speeds with direct-current machinery introduce certain commutating difficulties, particularly when dealing with heavy loads.

In plants where a large portion of the exhaust steam can be utilized, a reciprocating unit may be a better paying investment than a turbine. The engine can be used as a reducing valve and operated with a low back pressure. The turbine operates better with a vacuum, and this would entail the use of live steam passed through a reducing valve, which is a rather expensive way to secure low-pressure steam.

For the ground area occupied, there are a number of charts which have appeared from more or less interested sources, most of them demonstrating the economy of the turbine in this respect. It is true that the actual number of sq. ft. occupied may be less for the turbine than for any other type of prime mover and generator, but in many cases the actual area occupied by the unit itself is not the governing feature. When it comes to a question of crowding the most generating capacity into the least possible ground area the reciprocating engine is not very far behind the turbine, even in large units. Vertical-inverted and grasshopper-type marine engines have been built in very large sizes and occupy very little floor area.

Coal-handling equipment is another factor and the local conditions in some cases permit the coal to pass by gravity from the car to the bunker and thence to the fire and the ashpit and the dump. There are, however, not many cases where this scheme is feasible. The important factors are to simplify the machinery as much as possible and at the same time arrange it so that it can be operated by the fewest attendants. Each case presents its own peculiarities. This portion of the equipment will range in cost from 2 to 5% of the total.

The switch gear for controlling the electric power in many ways is the weakest link in the chain. Some of the biggest generating stations, those which would normally be supposed immune from serious interruptions, due to this portion of their equipment, have been completely put out of service for periods of time ranging from a few minutes to several hours or more. This part of the equipment will cost from 2 to 10% of the total plant cost.

Double-busbar system is advisable where continuity of operation is of greatest importance. True, this method duplicates a part of the control apparatus and is more costly than the single-busbar system, and its entire value depends upon the price one is willing to pay to minimize possible shutdowns. The Seventy-fourth street power plant of the Manhattan Railway Company, now the Inter-

borough Rapid Transit Company, New York, was upon one occasion tied up completely for some time by a piece of wet newspaper which landed where it could cause the greatest amount of trouble.

Barometric or jet type of condenser costs about 60% less than a surface condenser and the cost of maintenance is less. The local water-supply conditions will have to be considered in connection with this question. Where salt cooling water must be used the condenser discharge cannot be utilized for boiler feed and the large amount of water required may under such conditions make the surface condenser the cheaper. In many localities it is possible to arrange the circulating system of a surface condenser so as to take advantage of the siphon effect of a balanced water column and in this manner reduce to a minimum the amount of power required for cooling water; for after the water has been set in motion the circulating pump has only the friction head and the slight difference in head between the intake and outfall chambers to overcome.

Relative advantages of steam or electrically driven auxiliaries have been threshed out a number of times. The steam from auxiliaries can be used to heat the feed water, and this is one of the most powerful arguments in favor of the steam-driven unit; in fact, within reasonable limits, the more steam used in the auxiliaries the hotter the feed water, and the relative economy of the steam auxiliaries combined with the heater will far surpass other methods of drive as all of the heat units which are not used in the auxiliary engines are returned to the boiler. Electrically driven auxiliaries, on the other hand, increase the load upon the main units, and should any serious electrical disturbances arise these vital parts of the equipment may fail at the moment when their continuous operation is absolutely necessary to keep the plant going. The only way an electrically driven auxiliary can be rendered absolutely safe is to insure for it a supply of current which does not depend upon the operation of the main generators. A special generating unit might be installed for this purpose.

Cost of Constructing Steam-Driven Electric Power Plants. Frank Koester gives the following data in Engineering News Dec. 19, 1917. The cost of steam power plants is determined by the location and by the character of the building and equipment. The amount of capital available also plays an important part in determining the equipment. Mistakes have been frequent in selecting the type and size of various portions of the equipment, and in such cases it has been evident that the use of other machinery (perhaps lower-priced) would bring better results.

The figures given herein represent an average arrived at by the comparison of costs of various plants with which the writer has been connected, directly or indirectly in one way or another during a considerable experience in the design and erection of such works. The costs represent recent practice and are quoted per kw. capacity.

Building. Judgment in the architectural treatment and the selection of stock sizes of doors and windows will very materially keep down the first cost of the building. Comparatively the cost of the superstructure for a plant of small capacity will be greater per kw.

capacity than the cost of the larger plant. The superstructure for plants up to 5,000 kw. capacity costs from $15 to $25 per kw. The former figure may be secured by a compact arrangement with walls of common brick, wooden doors and window frames, steel roof trusses supported by the walls and a roof of the cheapest fireproof construction, such as corrugated iron, tin, etc.

The other type of building, costing about $20 to $25 per kw., may be constructed of higher grade masonry with fireproof windows and doors, roof trusses carried by steel columns which at the same time carry the crane runway, and the roof itself consisting of reinforced concrete covered by tar and gravel.

The cost of the superstructure for large size plants usually runs from $10 to $20 per kw. These are constructed of a self-supporting steel skeleton and self-supporting walls. The superstructure at $20 per kw. may embrace multiple boiler floors while those at $10 per kw. cover single boiler floor plants only. In both cases coal bunkers are provided. In the lower cost building steel bunkers of five to eight tons capacity per running foot are installed. In the multiple boiler floor building the bunkers are made up of structural steel, the beams being filled in with masonry arches, the side walls also being of masonry filling.

Chimney. The cost of the chimney depends largely on the location of the plant, the proximity to the source of the particular kind of materials constituting an important factor, as the cost of transportation of materials is a large item, steel chimneys being cheaper in localities where transporation costs favor such construction.

Furthermore, the competition among builders of chimneys, and especially since the introduction of the reinforced concrete chimney, is so strong that a radial brick chimney may sometimes be had as cheap as a steel chimney or reinforced concrete chimney.

A radial brick chimney for large size power plants may be built from $1.75 to $2.25 per kw. Reinforced concrete chimneys and plate steel chimneys may cost from $1.50 to $2 per kw.

Coal and ash handling systems. The cost of coal and ash handling systems is difficult to determine, depending so largely as it does upon the manner in which the coal is received from the shipper, the way the ashes are disposed of and the distance through which the coal as well as the ashes must be handled. Experience shows that the figures for equipment for handling coal and ashes range from $1.50 to $3 per kw.

Boilers. The cost of water tube boilers ranges from $8 to $10 per kw., depending upon the square feet of heating surface in the boiler. These figures do not include mechanical stokers, for which from $2 to $3 may be assumed. Breeching, of course, is also a separate item and varies considerably as to cost per kw. The boiler setting is included in the cost of boiler given above.

Blowers. In many of the modern power plants, especially plants for railway purposes, forced or induced draft is adopted. The blowers are usually steam-driven. The cost of such equipment is about $1 per kw.

Economizers. Where economizers are installed of sufficient capa-

city to heat the water to 200 deg or 220 deg. F. such apparatus costs about $2 per kw., provided that there are not too many additional smoke flues necessary for by-passing, etc.

Boiler feed pumps. The cost of such pumps alone is some 50 cts. per kw. When storage tanks are necessary the cost of the combined outfit amounts to 75 cts. or $1, depending on the number and size of the tanks.

Piping. In some stations piping has been installed for $2 per kw., while in others as high as $6 per kw. has been paid. This includes all high and low-pressure piping (steam and water).

For plants varying from 10,000 to 20,000-kw. capacity, the piping system not being elaborate but sufficient for continuous operation, $2.50 to $2.75 has covered the cost. This includes a high grade of covering for steam piping valued at about 20 cts. per kw.

Prime Movers. While the price of the prime movers varies with the size of the units, it also varies with the type of machine. The price of turbines is often governed by the price of reciprocating engines, although the former can be produced cheaper than the latter. Although the condensers for a turbine cost more than for a reciprocating engine the complete turbine generating unit ordinarily should cost considerably less. A 5,000-kw. turbo-generator should cost from $20 to $22 per kw. Reciprocating engines of this capacity are sold roughly at the same price, and about $10 per kw. needs to be added for the generator. The total cost for smaller units, 600 to 3,000 kw. capacity, is from $20 to $25 per kw., whether they consist of turbine or reciprocating-engine apparatus.

Condensers. The cost of condensers depends very much upon the vacuum desired and on the type of condenser. The cost of jet condenser equipment runs from $3 to $5 per kw., depending upon the type of pump used. The cost of surface condenser apparatus will vary from $5 to $8, depending partly upon the vacuum to be carried and whether the casing necessary forms part of the condenser equipment or is provided as part of the turbine shell, as is the case in the Curtis base-condenser turbine, in which case the above figures may fall as low as $3 per kw.

Exciters. A steam-driven exciter unit costs from 35 cts. to 40 cts. per kw. If a condenser should be installed in connection with it the cost may run as high as 70 cts. per kw., assuming that the exciter capacity is, approximately, 1% the total capacity of the plant.

Switchboards. In considering the cost of a switchboard equipment only such switchboard is herein considered as is necessary for the operation of the plant and the outgoing feeders, not including substation boards. The cost will vary with the voltage adopted for the system. For a high tension voltage the cost will run from $2 to $3.50, while for a low tension voltage (2,300 volts and lower) the switchboard equipment may be obtained for $1 to $2 per kw., depending largely upon the system of wiring adopted.

Miscellaneous. There are many other items, which must be figured in the complete cost of the plants, such as traveling cranes, which will amount to 25 or 50 cts. per kw. Smaller items like house

pumps, water meters, blow-off tanks, painting, supervision, etc., may total from $1 to $2 per kw.

Summary. To the summarized costs (see table XXVI) there needs still to be added the engineering fee which in many cases is figured as a percentage on the total cost.

TABLE XXVI. RELATIVE COSTS OF TURBINE AND ENGINE PLANTS

	Steam-turbine plants per kw.		Steam-engine plants per kw.	
Excavation and foundation	$ 2.00	$ 2.50	$ 3.00	$ 5.00
Building	10.00	15.00	10.00	20.00
Tunnels	1.75	4.00	1.50	2.75
Flues and stacks	2.50	3.50	2.50	3.50
Boilers and stokers	8.50	12.00	8.50	12.00
Superheaters	2.00	2.50	1.75	2.25
Economizers	2.00	2.25	2.00	2.25
Coal- and ash-handling system	1.50	3.00	1.50	3.00
Blowers and ducts	1.00	1.50	1.00	1.50
Pumps and tanks	1.00	1.25	1.00	1.25
Piping, complete	2.25	4.50	2.50	5.00
Turbo-generators	22.00	25.00	...	...
Engines	...	...	18.00	22.00
Generators, engine type	...	...	10.00	12.00
Condensers, surface	5.00	8.00	...	...
Condensers, jet	...	...	3.00	5.00
Exciters	0.75	1.00	0.75	1.00
Cranes	0.25	0.50	0.25	0.50
Switchboard	2.00	3.50	2.00	3.50
Labor	1.00	2.00	1.00	2.00
Total cost per kw.	$65.50	$92.00	$70.25	$104.50

It should be noted that the first column of figures in each case represents costs which are exceptionally low and may be attained under favorable conditions with engineering skill. The second column of figures represents fair average figures as ascertained from the costs of a number of plants recently erected. However, plants have been installed which cost as much as $125 per kw., and in an exceptional case the cost approximated $150 per kw.

All of these figures represent costs of plants of large capacity. Small plants of about 3,000 kw. capacity have been erected in the West at from $120 to $130 per kw., which costs may be reduced if a simple combination of machines is provided.

Referring to these tables, it will be observed that the turbine plant varies from $65 to $92 per kw. The main items constituting this difference are: building, turbo-generators and condensers. The difference in cost of these is due to the type of turbine, the size and make of condensers and their auxiliaries, as well as the manner of assembling, all of which may reduce the size of the building required.

The difference in cost of boilers is due to the make or type and the rating of the boiler h.p. adopted by the plant designer per kw. capacity. This ratio varies greatly. Plants have been installed with the same type of boiler and the same type of prime mover in which the ratio varies, one value being 0.60 boiler horse-power per kw. gen-

erator capacity, while in other cases it is 0.75, and 0.80. This difference depends upon the experience and judgment on the part of the designer as well as the estimated ability of the future available operating force to produce steam effectively.

The difference observed in the cost of the other items may be explained by the difference in the grade of material used and the ability of one purchaser over another to secure the lowest market price.

Average Construction Costs of Steam Turbo-Electric Power Plants. (Engineering and Contracting, Mar. 6, 1912). The average range of costs of constructing steam turbo-electric plants is given in a discussion before the Engineers' Society of Western Pennsylvania by O. S. Lyford, Jr., and R. W. Stoval of Westinghouse, Church, Kerr & Co. The plants are assumed to have no other equipment than that required efficiently to produce alternating currents. Bituminous coal is the fuel assumed to be used. The costs are shown in Table XXVII, and the authors explain the several items as follows:

Some of the group costs in this table do not have any very specific relation to the kilowatt capacity installed in the plant and the probable range in such costs is a matter of experience with previous cases. This refers to such groups as "Preparing Site," "Yard Work," "Electrical Switching Equipment" and "Service Equipment." For instance, the main item of cost coming under the "Yard" group is generally that of condensing water flumes exterior to the building and it will be readily understood that this cost is affected much more by the relative location of the building to the water supply and by the character of work required than by the actual size of the plant.

Similarly the electrical switching equipment costs depend much more on the extent and the scope of the electrical distributing system than upon the actual capacity of the plant. Again the largest item of the "Service Equipment" costs, namely, that of coal handling, depends upon the existing physical conditions much more than upon the capacity.

Some of these cost groups, however, can be reduced to other units than that of the kilowatt, and this permits a clearer understanding of their range.

The foundation costs, for instance, will run from $1.25 to $4 per sq. ft. of building plan area, depending on the character of the soil; the lower cost covering simple concrete footings on thoroughly good bearing soil, while the necessity for piling, water-proofing, excessive rock excavation, etc., will run this cost toward the higher limit. Then the plan area will vary from 0.8 to 1.5 sq. ft. for each kw. of capacity installed, depending upon the size of the units and upon their arrangement; the combined effect of these two cost ranges giving the range in price per kw. shown on the table.

The building cost will vary from 8 cts. to 12 cts. per cu. ft. of overall building volume, according to the size of the building, and the character of construction and the local price of building materials and labor. Depending again upon the size of the units and

upon the efficiency used in arranging them, there will be required from 50 to 100 cu. ft. of volume per kw. of capacity. The combined effect is to make the building costs range from $4 to $12 per kw. as shown.

In boiler room equipment the cost of materials and labor will generally be between $30 and $40 per nominal boiler h.p., and generally there will be installed between 0.4 and 0.6 boiler h.p. per kw. of capacity, resulting in the cost range shown in table XXVII.

TABLE XXVII. COST OF STEAM TURBO-ELECTRIC GENERATING STATIONS

2,000 to 20,000 kw. capacity, based on maximum continuous capacity of generators at 50 deg. rise.

	Per kw. High	Per kw. Low
Preparing site: Dismantling and removing structures from site, making construction roads, tracks, etc.	$ 0.25	$ 0
Yard work: Intake and discharge flumes for condensing water, railway siding, grading, fencing, sidewalks, etc.	2.50	1.00
Foundations: Including foundations for building, stacks and machinery, together with excavation, piling, waterproofing, etc.	6.00	1.00
Building: Including frame, walls, floors, roofs, windows and doors, coal bunker, etc., but exclusive of foundations, heating, plumbing and lighting	12.00	4.00
Boiler room equipment: Including boilers, stokers, flues, stacks, feed-pumps, feed-water heater, economizers, mechanical draft and all piping and pipe covering for entire station except condenser water piping	24.00	12.00
Turbine room equipment: Including steam turbines and generators, condensers with condenser auxiliaries and condensing water piping, oiling system, etc.	22.00	12.00
Electrical switching equipment: Including exciters of all kinds, masonry switch structure with all switchboards, switches, instruments, etc., and all wiring except for building lighting	5.00	2.00
Service equipment: Such as cranes, lighting, heating, plumbing, fire protection, compressed air, furniture, permanent tools, coal and ash handling machinery, etc., etc.	5.00	2.50
Starting up: Labor, fuel and supplies for getting plant ready to carry useful load	1.00	0.50
General charges: Such as engineering, purchasing, supervision, clerical work, construction, plant and supplies, watchmen, cleaning up, etc., etc.	6.00	3.00
Total cost of plant to owner, except land and interest during construction	$83.75	$38.00

From this table it is seen that the cost of such stations under normal conditions may range in price from $40 to $85 per kw. of maximum continuous generator capacity. So far known to the writers, no stations have as yet been built for the lower figure, for this minimum is possible only with an extremely fortunate combination of circumstances, such as natural advantages of location combined with most favorable sizes and arrangement of apparatus.

It is apparent from this table that there may be a very large

difference in the first costs of two stations of the same size, and that this may be the case, even though the two stations have been designed and built with equal ability and economy.

Unit Costs of a Large Steam Station in Ohio. J. C. Lathrop in Electrical World, Aug. 30, 1913, gives the following costs of the steam station of the Northern Ohio Traction & Light Company at Cuyahoga Falls.

Items of station	Total costs	Cost per boiler-hp.
Foundations, excavation, etc., including condensing water tunnels	$170,000	$ 17.60
Portion of dam, construction, tracks, etc.	50,000	5.20
Superstructure	109,000	11.30
Structural steel	43,000	4.45
Coal bunkers, including structural steel, concrete, chutes, etc.	112,000	11.60
Electrical equipment of station, including turbines	245,000	25.40
Crane	6,000	0.62
Condensers	41,000	4.25
Pumps	10,000	1.04
Feed-water heaters	6,000	0.62
Piping, heating and covering	40,000	4.15
Stack	13,000	1.35
Boilers	140,000	14.50
Breeching	11,000	1.14
Stokers	60,000	6.20
Minor instruments	10,000	1.04
Engineering and superintendence	50,000	5.20
Total	$1,107,000	$114.00

General Description of the Plant is as follows: The boiler room is 56 by 330 ft. and separated by a division wall is the turbine room (on the river side) 63 by 227 ft. The water of the Cuyahoga is dammed and used for condensing purposes. Coal is obtained from a railroad siding which runs along the top of the bank about 90 ft. above the boiler-room floor. The coal is handled through a standard trestle with individual bunkers for each boiler. It passes through Richardson automatic scales so that a fairly accurate record of the amount delivered to each boiler is kept.

Foundations are concrete on solid rock, or on a compact shale with a massive concrete wall 24 ft. high on the river side; the remaining foundation walls for the building being 2 ft. 6 ins. deep, except where they stepped up at the ends of the turbine room.

Intake and discharge tunnels were built in a trench cut in solid rock by a standard channeling machine.

The exterior walls of the building are of paving block, the trimmings, moldings, window architraves, copings, etc., were furnished in gray architectural terra cotta having a tooled surface. The window sashes are of solid steel sections throughout. Those in the turbine room are glazed with polished plate glass, while all others are glazed with AA double-strength glass. The boiler-room monitors are glazed with ribbed wire glass in continuous steel sashes, which swing from the top and are opened or closed in sections by devices operated from the boiler-room floor. In the

center of the turbine-room basement is a steel rolling door large enough to admit standard railway cars. The entire surface of the turbine-room walls under the crane runway girders is finished with a marble-like material called "Vitrolite," and all interior ironwork is painted a light gray. All floors in the turbine-room have a granulithic finish. Lamp circuits are carried in conduits back of the wall facing, except above the crane runways.

A switchboard gallery about 40 ft. long is located in the center of the turbine room.

Structural Steel framing is independent of the walls and was erected complete before the general construction was started. I-shaped plate and angle columns, and roof trusses of the "Fink" type were used over the turbine room, and ordinary flat-top trusses over the boiler room. The crane runway girders were of built-up sections, reinforced laterally by 15-in. channels on the top flange. The turbine-room roof was of Spanish tile laid on a reinforced-concrete slab, the boiler-room monitors were covered with the same tile, while the general surface of the boiler-room roof has a standard tar and gravel surface over concrete.

The Boiler-Room contains 16 604-h.p. B. & W. boilers and superheaters, arranged in one row and equipped with Taylor stokers and Sturtevant fans, driven by Sturtevant engines, regulating the speed of the fans directly from the steam pressure. Each boiler has recording instruments for coal consumption (Richardson 200-lb. automatic scales), CO_2 recorders, draft gages and steam-flow meters, recording thermometers and automatic feed-water regulators.

Coal Pockets are provided with dumping gates to handle a carload at one time.

The Stack, built by the Custodis Chimney Construction Company, is 275 ft. high and 16 ft. in diam. inside at the top.

Steam Piping System provides that the boilers may be divided into 4 groups, any of which may be out of service at any time, but no effort was made to design a duplicate system of piping. The main-station header was made in lengths of about 36 ft. All nozzles, including the 12-in. leads to the turbine, were welded on by an electric arc. Van Stone flanges were used throughout on all high-pressure piping 4 in. and above in diam. Cast-steel fittings were used on all high-pressure superheated steam lines, and all high-pressure superheated steam valve bodies were made of cast steel, while the disks, seats and stems were of monel-metal. All high-pressure and low-pressure steam piping has 85% magnesia covering.

The main turbine exhausts are 36-in. diam. and pass through a division wall and vertically alongside the stack and terminate above the turbine-room roof in a standard exhaust head.

Water Storage. A 50,000-gal. steel tank is set on a bluff above the station with a head of about 100 ft. and supplies the general service water, the cooling water for transformers, the water lines for cooling ashes and the fire lines. These fire lines are connected to the *feed-water* lines so that in case of fire one of the feed pumps

can be used as a fire pump. Duplicate 6-in. feed-water mains are filled by the 3 feed-water pumps, which take water from the hot-well or discharge tunnel, one of which contains a 6-in. Venturi meter. A separate system for condensing water, with standard air and oil piping with convenient taps, etc., is provided.

The Turbine-room is equipped with a 50-ton Morgan crane, with a 50-ton hoist and an auxiliary 5-ton hoist, 4 motors on a 500-volt d.c. circuit.

Electrical Equipment comprises 3 Westinghouse 6300-kw., 2,300-volt, 60-cycle, 3-phase turbo-generators, 1,800 rev. per min., connected with 3 Westinghouse horizontal double-flow steam turbines. The contractors have guaranteed a steam consumption of 14.8 lbs. per kw.-hr. at 100% rate and 15.4 lbs. at 150% rate. There are 2 150-kw. steam-driven exciters placed on the turbine-room floor between main units and directly in front of the main switchboard. The exhaust steam from the turbines discharges into Westinghouse Le Blanc condensers, which are located in the basement. Circulating and air pumps for these condensers are on a single shaft and are driven by a 228-h.p. Westinghouse steam turbine. Auxiliary Alberger single-stage booster pumps were provided in the turbine-room basement, driven by 75-h.p., 2300-volt, 3-phase Westinghouse motors. 3 boiler-feed pumps are provided in the basement, having a total rating of 1,000 gals. per min., all interconnected and suitably valved, which take their water normally from 3 Hoppes feed-water heaters, and have an additional suction line in both a hot and cold well. These feed-water heaters are filled by 2 300-gals. per min. turbine pumps directly connected to Westinghouse motors.

Main cables from the generators are carried under the turbine-room floor to the 2300-volt busbar, from which bus cables lead to 3 3,000-kw. transformers in the turbine-room basement, stepping up to 22,000 volts for the outgoing high-tension lines that feed the substations. No. 3 substation is located in the northwest corner of the turbine-room and consists of 3 500-kw. Westinghouse single-phase, 60-cycle rotaries and 3 step-down transformers which are fed directly from the 2,300-volt main busbar.

The foundation work and excavation for this structure was done by the company on a force-account basis. The other work was installed by contract.

Cost of Equipment for Isolated Plants. D. F. Atkins and H. M. Price in Electrical World, Aug. 3, 1912, give the following unit costs which are used in estimating the cost of mechanical equipment of federal buildings under the control of the Treasury Department.

	Cost in place, per kw.
Single-valve, direct-connected simple engines and generators	$35
Single-valve, direct-connected compound engines and generators	45
Four-valve, direct-connected simple engines and generators	45

	Cost in place, per kw.
Four-valve, direct-connected compound engines and generators	55
Water-tube boilers and setting, with breeching and stack	30
Switchboard and mountings, per panel	300

Pipings, pumps, feed-water heater, etc., in place, at 20% of the cost of the boilers, engines and generators.

Cost of Elements of Small Steam Electric Power Plants. The following table, based on the personal experience of P. R. Moses in New York and vicinity, was published in Isolated Plant, December, 1908.

	Cost per kw. plant capacity
Boilers (erected and set in masonry):	
Horizontal-tubular	\$14–\$18
Water-tube	16– 20
Steam engines:	
High speed, simple direct-connected	20– 25
Medium speed, compound non-condensing direct-connected	28– 35
Low speed, compound condensing, belted	20– 25
Low speed, simple, slow speed, belted	25– 30
Gas engines	50– 60
Oil engines	75– 85
Gas producers	15– 20
Dynamos:	
Direct-connected to high-speed engine	13– 16
Belt-connected to engine	12– 15
Direct-connected to Corliss engine	16– 20
Switchboard	5– 10
Foundations	5– 10
Steamfitting — including auxiliary apparatus — such as feed heater, grease separator, exhaust head, tanks, covering, etc.	20– 30

Checking Power Plant Construction Cost Estimates by Percentages. F. W. Gay, mechanical engineer for J. G. White and Co., in the Journal of the Worcester Polytechnic Institute, March, 1913, shows a method of checking estimates and confining the greatest chances of error to minor parts of the installation.

According to his scheme, the first work is in the determination of the relative importance of the various items to be covered by an estimate. From his experience, he has compiled data and prepared diagrams covering power plants from 2,000 to 40,000 kws. in capacity.

The diagrams show that: *engines and foundations* constitute from 33.6% to 61% of the total equipment cost; an average of 50%. *Boilers, settings and foundations,* from 17.25% to 31.5%, average about 25%. *Piping, complete,* from 7% to 17%, averages about 11%. *Condensers, complete with foundations and auxiliaries,* 10% to 15%, average at 11%. *Circulating-water system,* 4.5% to 8%, averages 6.5%. Thus in these 5 groups is a minimum of 72.35% of all apparatus items, leaving the remainder, 27.65%, to be divided among at least eleven groups, including "miscellaneous." If, therefore, the greater part of the allowable time is spent on these 5 groups he believes that the result will justify the expenditure of time and money.

Boilers, foundations and settings can be estimated closely, as can also the condensing apparatus. Engines, foundations, piping and circulating-water systems present greater difficulties, relatively, about in the order named. He finds it possible to estimate as close as 3% *on boilers, installed; on engines, installed,* as close as 5%; *on engine foundations,* as close as 10%; *on circulating-water systems* as close as 15%; *on piping systems,* as close as 20%; *on condensers, auxiliaries and foundations,* as close as 3%.

Applying these percentages of error to the minimum percentages of the whole, he has the total probable error on 72.35% of the apparatus as follows:

Boilers	17.25 x 0.03 = 0.52%	(plus or minus)
Engines	33.60 x 0.06 = 2.01%	(including foundations)
Piping	7.00 x 0.20 = 1.40%	
Condensers	10.00 x 0.03 = 0.30%	
Circ.-water system	4.50 x 0.15 = 0.68%	
Total	4.91%	

He assumes, for discussion, that one must estimate on the total cost as close as 15%, which percentage ordinarily includes 5% for contingencies and errors. By concentrating attention on the five principal groups, he thinks he can come as close as 5% on the larger items, and has then a leeway of about 43.5% on the remaining items. He believes it possible, in almost every case, to come within 20% on these items, and then the total estimate is within 8.5%, as against the 15% assumed.

Buildings for this apparatus vary from 6% to 16% of equipment costs, an average, say, of 10%. Using unit prices, *on a square- and cubic-foot basis,* as well as, for *h.p. and kw. bases,* checking each against the other, he thinks enables him to keep his error within 10 to 15%, or 1% or 1.5% on the total.

In his practice he has used the minimum percentages for the principal items. In some cases this is as high as 85%, and by analyzing this in the same manner as for the 72.35% the total estimate may be within 6.5%.

Referring to one contract recently finished, he states that the final figures from the cost analysis show that the estimate was in error less than 2.5%.

Cost of Five Substations. The following cost data are based on the company's construction and purchase records, including allowances for fixed charges as indicated in the inventory of Sloan, Huddle, Feustel and Freeman published in Electric Railway Journal, Jan. 22, 1916. The 5 substations, of which detailed costs of land, buildings and equipment are given for 2, receive energy at about 13,000 volts, 25 cycles, and deliver direct current at the usual trolley pressures of 550 volts to 600 volts. They were built about 10 years ago, and the investment cost new is the total outlay the company had made on Nov. 1, 1914, in the construction of this portion of its system. The fixed charges listed are those incurred during construction, and the figures show, as nearly as may be, the actual investment the company has made in the five substations tabulated.

COST OF SUBSTATION BUILDINGS

BRIDGEWATER (900 KW.), 35 FT. 2 IN. BY 60 FT. 6 IN.

Item and quantity		
Excavation, 476 cu. yd. at $	$ 0.50	$ 238
Concrete foundation, 170 cu. yd. at $	14.00	2,380
Concrete — 3-in floors — plain, 1200 sq. ft. at $	0.16	192
Concrete — 6-in. reinforced floor, 417 sq. ft. at $	0.50	208
Concrete — 3-in. reinforced floor, 349 sq. ft. at $	0.25	87
Concrete — 4-in reinforced floor, 119 sq. ft. at $	0.35	42
Concrete — 10-in. reinforced floor, 984 sq. ft. at $	0.60	590
Concrete steps, 12 cu. ft. at $	0.35	4
Brick — walls, 74,000 at $	24.00	1,776
Brick — coping and pilasters, 9000 at $	26.00	234
Cut stone, 193 cu. ft. at $	2.50	482
Steel and iron — structural steel, 13,531 lbs. at $	0.04	541
Steel and iron — wrought-iron railing	...	20
Steel and iron — miscellaneous	...	260
Timber — roof sheathing, 7200 ft. b.m., at $	41.00	295
Timber — miscellaneous	...	5
Roofing — slate, 2860 sq. ft. at $	0.10	286
Millwork — doors, 214 sq. ft.	...	101
Millwork — windows, 473 sq. ft.	...	228
Screens, 232 sq. ft. at $	0.15	35
Sheet metal work, $517; lighting, $393	...	910
Heating, $18; plumbing, $175	...	193
Painting — oil, 583 sq. yds. at $	0.18	105
Painting — cold water, 402 sq. yds. at $	0.12	48
Fence	...	57
		$9,317
Engineering, interest, insurance and contingencies, 11%, $1025; taxes, organization, 3.5%, $326		1,351
Total building cost		$10,668
Total building cost per kw.		$11.83

Buildings, brick and concrete, walls being brick and floors plain and reinforced concrete. Roof supported by steel trusses and covered with slate. Present condition good.

BROCKTON (3750 KW.), 34 FT. 8 IN. BY 78 FT. 10 IN.

Item and quantity:		
Excavation 599 cu. yd. at $	$ 0.60	$ 359
Trenching, 91 cu. yd. at $	0.75	68
Concrete — plain footings, 154 cu. yds. at $	14.00	2,156
Concrete floor 6 in. 2733 sq. ft. at $	0.18	492
Concrete curbing, 72 cu. ft. at $	0.30	22
Concrete — 3-in. walk, 90 sq. ft. at $	0.16	14
Concrete — 4-in. reinforced floor, 209 sq. ft. at $	0.40	84
Concrete — 6-in. reinforced floor, 301 sq. ft. at $	0.50	150
Brick — walls, 109,000 at $	24	2,616
Brick — pilasters, 53,000 at $	26	1,378
Cut stone, 510 cu. ft. at $	3	1,530
Timber	....	291
Millwork — doors, 381 sq. ft.	....	173
Millwork — windows, 1263 sq. ft.	....	622
Millwork — screens, 360 sq. ft.	....	54
Cast iron, 5113 lbs. at $	0.04	205
Railings, etc.	....	144
Steel, 37,617 lbs. at $	0.05	1,881
Slate, 153 sq. ft. at $	0.90	138
Roofing — tar and gravel, 2607 cu. ft. at $	0.07	182

Sheet metal	....	308
Grating, 266 sq. ft. at $	0.35	93
Ventilators, $20; El Lighting, $386	....	406
Heating, $95; Plumbing $175	....	270
Painting — oiling, brick	....	150
Painting — cold water, 1362 sq. yds. at $	0.12	163
Painting — oil, 498 sq. yds. at $	0.18	90
		$14,039
Overhead, as above, 14.5%		2,036
Total building cost		$16,075
Total building cost per kw		$4.29

Building has brick walls, floors plain and reinforced concrete; roof supported by steel trusses, covered with tar and gravel. Plant in good condition.

Taunton substation, brick and concrete building, 45 ft. by 88 ft., with brick walls and concrete floors, all in good condition.

Fall River substation, irregular building, converted power house, about 86 ft. by 146 ft., approximately 12,000 sq. ft.

Rockland substation building, 31 ft. by 60 ft., brick, concrete and steel.

COST OF EQUIPMENT

BRIDGEWATER (900 KW.)

Items		
3 300-kw. GE rotary converters at $	$4,570	$13,710
3 330-kw. GE three-phase, air-cooled transformers at $	2,512	7,536
2 40-in. motor-driven Buffalo blowers at $	165	330
1 GE motor-driven air compressor and equipment at $	375	375
4 12,500-volt GE electrolytic lightning arresters at $	300	1,200
Switchboards and wiring	....	7,647
Miscellaneous equipment and tools	....	195
Total		$30,993
Engineering, insurance, contingencies, interest, 10.5%, $3254; taxes and organization, 3.5%, $1085		4,339
Grand total		$35,332
Grand total equipment per kw.		$39.20

BROCKTON (3750 KW.)

3 750-kw. GE rotary converters at $	$10,085	$30,255
1 1500-kw. GE rotary converter at $	10,578	10,578
3 825-kw. GE three-phase air-cooled transformers at $	3,872	11,616
1 1575-kva. GE three-phase air cooled transformers at $	4,393	4,393
1 12,500-volt GE electrolytic lighting arresters at $	358	358
2 70-in. Buffalo motor-driven blowers at $	375	750
1 GE motor-driven air compressor and equipment at $	375	375
Switchboards and wiring	....	16,292
Miscellaneous equipment and tools	....	93
1 10-ton hand-operated traveling crane at $	1,350	1,350
Total		$76,060
Overhead as above, 14%		10,648
Grand total		$86,708
Equipment per kw.		$23.20

SUMMARY OF SUBSTATION COSTS

Substation	Kw. capacity	Land	Building	Equipment	Total, ex. Land	Grand Total
Bridgewater ..	900	$ 1,296	$10,668	$35,332	$46,000	$47,296
Brockton	3,750	2,488	16,075	86,708	102,783	105,271
Fall River ...	3,000	20,507	28,200	81,307	109.507	130,014
Rockland	900	1,188	12,783	35,968	48,751	49,939
Taunton	1,700	4,644	17,088	59,639	76,727	81,371
Total	10,250	$30,123	$84,814	$298,954	$383,768	$413,891
Average per kilowatt		$2.92	$8.25	$29.20	$37.45	$40.37

Cost of Sub-Stations. (Data, Aug., 1915.) H. W. Young gives the total net cost of steel tower 3-phase outdoor sub-stations with three single-phase 33,000 to 2,300 volt transformers.

Station capacity, kw.	No. of trans.	25 cycle station per kw.	Total cost	60 cycle station per kw.	Total cost
45	3–15 kw.	$35.50	$1,597.00	$29.35	$1,321.00
60	3–20 "	28.50	1,710.00	23.55	1,415.00
75	3–25 "	24.50	1,837.00	20.65	1,550.00
90	3–30 "	21.50	1,935.00	17.65	1,589.00
120	2–40 "	16.75	2,010.00	13.80	1,656.00
150	3–50 "	14.25	2,137.00	11.90	1,785.00

Net costs include all high tension bus bar supports, copper tube bus, high and low tension dead ends and a galvanized steel tower with footings.

Mr. Young is also authority for the net cost per kilowatt for equipment of electric sub-stations, of the outdoor type, equipment for 3-phase current and voltage range from 2,300 to 33,000.

Station capacity, kw.	No. of transformers	Transformer, 25-cycles	Cost per kw. 60-cycles	Cost per kw. of high tension switching and protective units
45	3–50 kw.	$25.00	$20.00	$6.25
60	3–20 "	20.50	16.50	4.75
75	3–25 "	18.00	15.00	3.80
90	3–20 "	16.00	13.00	3.10
120	3–40 "	12.50	10.50	2.50
150	3–50 "	11.00	9.00	2.00

Cost of Sub-Stations. The following costs are from construction reports of a power company in California in 1908. In each sub-station oil cooled transformers were installed for the lighting, and water cooled for the power circuits.

55,000–66,000 TO 2,300 VOLT STATIC TRANSFORMER STATIONS

Kw. capacity Oil cooled	Kw. capacity Water cooled	Cost of building	Cost per kw.	Cost of equipment	Cost per kw.	Total cost per kw.
3650	4325	$12,489.85	$2.85	$29,669.94	$6.87	$9.72
2400	3075	9,152.60	2.85	30,534.48	9.92	12.77
1500	1875	10,979.90	5.85	23,774.49	12.65	18.50
1500	1875	7,236.28	3.86	19,023.29	10.15	14.01
1500	1875	7,344.96	3.92	14,732.10	7.90	11.82

Comparative Costs of Indoor and Outdoor Types of Sub-Stations. The following costs are derived from a paper by K. C. Randall, Trans. A. I. E. E. Vol. XXVIII, year 1911.

TRANSFORMER SUB-STATIONS

2,000 kva. 25,000 volt, 60 cycles.

	Indoor	Outdoor
Building	$ 5,400	$1.020
Transformers	7,200	7,800
Switchboard	2,500	2,625
	$15,100	$11,445
Per kilovolt-ampere	7.55	5.72

MOTOR-GENERATOR SUB-STATION

3,000 kva. 22,000-3,000 volt, 25 cycles

	Indoor	Outdoor
Building	$ 21,835	$7.480
Transformers	15,000	16,000
Motor-generators	48,000	48,000
Exciters	4,500	4,500
Switchboard	20,000	20,200
	$109,335	$96,180
Per kilovolt-ampere	36.45	32.00

Area per h.p. Occupied by Various Power Groups. Table XXVIII after Mr. R. E. Mathot in Engineering Magazine, January, 1907, gives the area per h.p. occupied by various plant groups.

TABLE XXVIII. AREA OCCUPIED BY VARIOUS POWER UNITS

Type of engine	Hp.	Total space occupied by all apparatus and passage-ways, sq. ft.	Area per hp. sq. ft.
Producer-gas motor	200	1,620	8.1
Stationary engine and boiler	100	1,000	10.0
Producer-gas motor	100	680	6.8
Semi-portable steam engine	150	475	3.2
Two producer-gas motors	50 + 30	1,050	13.1
Semi-portable steam engine	50	420	8.4

Floor Space Required for Different Kinds of Prime Movers for Various Capacities of Plant. The diagram, Fig. 12, was prepared by Mr. E. H. Sniffen in 1902.

Reconstruction Cost of a Storage Battery Plant. Electrical World, May 31, 1913. Charles A. Hobein in the Iowa Engineer gives the following cost of reconstructing a storage battery of the United Railways Company, St. Louis, in which, after 6.5 years' operation the plates were nearly worn out and the batteries very inefficient.

Originally there were 2 batteries rated at 2,500 amps. per hr. each. The tanks were of yellow pine and lined with lead .0625 in. thick. The electrolyte was dilute sulphuric acid of 1.210 specific gravity.

In the new installation each cell is an independent unit. Wooden blocks resting on bricks form the support for the insulators. There are 10 of these blocks and insulators under each tank. The space under the cells is clear so that a man can crawl under and replace any insulator or block. A new insulator was developed by the company. An annular space in the insulator contains oil. Any leakage would have to come down the center extension of the insulator, across the surface at the oil to ground. After 2 years' service the insulation is almost perfect. The new tanks without paneling have proved much stronger and do not require so many spacing insulators. The paneling of the old-type tanks was so

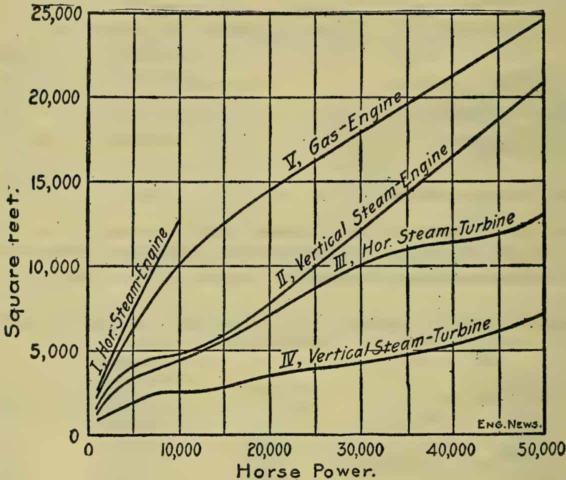


Fig. 12. Diagram of floor-space required for different kinds of prime-movers, for various capacities of plant.

constructed as to form a lodging place for acid drips, and the consequence was decay in the crevices.

The old tanks were removed to an upper floor, the lead lining removed, and after the lining had been inspected inside and out and repairs made if needed, the lining was installed in the new tank. All the old linings with a few exceptions were used over again.

The lead linings where they extend over the edge of the tanks were cut to form drip points. The point of each end was in the center and on the sides there were 4 points which came between the insulator spacing of the tanks. This scheme keeps the insulators free of acid from dripping.

A positive plate known as the Tudor type was used. They are practically pure lead plates, grid and active material, about .375-in.

thick. The surface is cut into horizontal rows of finely divided grooves. Between the .375-in.-wide horizontal rows was left a web of the lead which was not cut. The active material was formed in the finely divided grooves. These plates were very easily buckled and required very rigid separation. The board separators were equipped with 5 dowels each. The outside dowels were 1 in. wide by .5 in. thick. The other 3 were .5 in. wide by .5 in. thick. These separators were suspended from the top of the plates by means of a rubber peg pushed through the top of the center dowel. The hold-downs are semicircular glass pieces about 8 ins. long. Some of the old plates removed in the process of reconstruction did not have any of the active material remaining in them. Enough were found, however, to be sufficiently valuable to give a year's service in 50 cells.

TABLE XXIX. DATA OBTAINED FROM WATTMETER TESTS (One week's average).

	Before rebuilding	After rebuilding
Kw.-hr. efficiency, %	32.1	43.8
Amp.-hr. efficiency, %	45.3	51.3
Capacity discharge, amp-hr.	960	2,410

The negative plates are the plates from the original installation. They were found good for several years more of efficient service.

Some wattmeter tests made on one of the batteries before and after the reconstruction are recorded in Table XXIX. The weekly overcharge was distributed and charged to the amount of energy put into the battery, by adding ⅙ of the power required by the overcharge to the charge required by the battery, after a discharge, if a discharge occurred on 6 nights of a week following the overcharge.

COSTS OF ORIGINAL INSTALLATION AND RECONSTRUCTION

2 batteries installed complete with boosters, wiring switchboards and copper bars	$198,000.00
Cleaning out sediment, including pump, tanks, etc.	2,223.13
Reconstruction 1910 and 1911	107,321.88
Board separators complete with dowels each	0.15
Positive plates, each	4.00
Negative plates, each	3.65
Oil insulators, complete with alloy cap, each	0.40
Wooden tanks, railway company's manufacture, each	12.00
Lead linings, railway company's manufacture, each	15.00

Cost of Constructing a Turbo-Generator Power Plant, Transmission Line and Substructures. In 1910 an arrangement was made by which the Copper Queen Consolidated Mining Co. agreed to an enlargement of its power plant at Douglas, Arizona, to supply power for El Tigre mines, 65 miles away, in Mexico. In Western Engineering February, 1913, J. W. Malcolmson describes the new plant and gives in detail the construction costs. (Tables XXX–XXXIV.)

TABLE XXX. COST AND ERECTION OF POWER PLANT

Engineering:	
Engineers' salaries while engaged in drafting, blue-prints for foundations, piping, condensers, etc.	$ 477.98
Foundations:	
Excavation (labor)	$ 96.19
Anchor bolts (labor and material)	132.58
Molds (labor and material)	468.93
Concrete, 127½ cu. yds. (labor and material)	981.97
	$ 1,679.67
Hot well:	
Excavation (labor)	$ 72.94
Molds (labor and material)	46.86
Concrete, 15 cu. yds. (labor and material)	238.95
Pipe connections (labor and material)	167.14
Steel reinforcement (labor and material)	34.81
	$ 560.70
Steam turbo-generator:	
2 A.T.B. 4–750–1800 generators with Curtis steam turbines and accessories	$28,250.00
4 5-in compression and vacuum gages	11.20
Insurance on engine	70.62
Freight, Schenectady, N. Y., to Douglas	2,143.55
Labor erecting	906.51
Material for erecting	320.17
	$31,702.05
Switchboard:	
1 complete switchboard	$ 2,455.00
Insurance	3.89
1 Hartman & Braun frequency meter	52.20
2 d.c. voltmeters, range 0-150 volts; 2 d.c. ammeters, range 0-300 amp.; 2 d.c. ammeters, range 0-150 amp.	144.74
Freight to Douglas on above parts	267.25
Labor erecting	145.63
Material erecting	85.54
	$ 3,154.25
Wiring:	
75 ft. 552-lb. 3/250,000 C.M.V.C., 3/32 by 1/16 lead, 7/64 Sec. No. 1, complete; 30 ft. 52-lb. 3/8 wire, V.C. 5/64 by 1/16 lead, Sec. No. 1, complete 175 ft. 155-lb. 4/0 cable, R.C 5/64 T.B.W., Sec. No. 1, complete, S. O. N. 72143; 22 lb. No. 227 compound	$ 133.40
Freight on above	24.12
Labor erecting	117.28
Material for erecting	18.86
	$ 293.66
Condensers:	
2 72-in. type "B" Helander patent barometric condensers	......
2 12 by 24 by 16-in. dry air pumps	$ 7,100.00
Insurance	3.37
Freight on above	2,208.47
Labor erecting:	
Machine shop, 45 hr	22.88
Blacksmith shop, 6 hr	3.64
Carpenter shop, 114 hr	55.68
Rigging gang, 1,245½ hr	332.08

Electric gang, 384 hr.	146.83
Special gang, 158 hr.	33.23
Construction, 995½ hr.	400.52
	$ 994.86
Material for erection	133.31
	$10,440.01

Steam and motor exciters:

1 standard 30-kw. generator set, consisting of 1 9 by 9 VS. 7 automatic engine, complete with cylinders, lubricators, and full set of wrenches, extended sub-base for direct connection to 1 No. 10 C. h.p. 8 generator compound wound for 125 volts field rheostat	$ 1,125.00
1 2-brg. motor-generator set, consisting of one 30-kw No. 8 "L" type "S" generator coupled with 125 v. with bed plate and shaft, one No. 11 A.H. 45, 6-hp type "C.C.L." motor, 2300 volts with auto starter and oil	1,000.00
Insurance	3.87
Freight	244.27
Labor erecting	44.40
Material for erecting	9.29
	$ 2,426.83

Water piping:

Cost, Pittsburgh, Pa.	$ 3,522.87
Freight to Douglas	1,644.09
Labor laying and erecting	408.33
Material for laying and erecting	110.43
Material and labor for supports	1.23
	$ 5,686.95

Exhaust piping:

Cost, Pittsburgh, Pa.	$ 807.94
Freight to Douglas	336.88
Labor erecting	83.13
Material for erecting	33.92
Supports and hangers (labor and material)	29.11
	$ 1,290.98

Steam piping and separators:

Cost, Pittsburgh, Pa.	$ 7,717.41
2 16-in. Stratton separators	1,089.00
Freight on pipe and separators to Douglas, New York	1,478.87
Labor erecting	833.30
Material for erection	234.59
Supports and hangers	33.73
Pipe covering, erected	2,400.00
	$13,786.90

Air piping:

Cost, Pittsburgh, Pa.	$ 258.70
Freight to Douglas	71.16
Labor erecting	25.25
Material for erecting	37.05
Supports and hangers (labor and material)	1.61
	$ 393.77
Total	$71,893.75

NOTE. Weight of pipe and separators, 340,405 pounds.

TABLE XXXI. COST OF TRANSMISSION LINE

Poles:	
First cost	$ 8,642.18
U. S. freight	4,245.74
Unloading, hauling and delivery along line	3,730.57
Assembling and erecting	1,348.05
Digging holes and setting poles	8,610.97
Customs charges and duties	121.12
Mexican railroad freight (Douglas to Ysabal)	1,397.25
	$28,095.88
Transmission line — Cross-arms:	
First cost	$ 1,422.28
U. S. freight	446.10
Unloading, hauling and delivery along line	614.30
Customs charges and duties	13.78
Mexican railroad freight (Douglas to Ysabal)	112.12
	$ 2,608.58
Transmission line — Hardware (bolts and braces):	
First cost	$ 1,380.55
U. S. freight	429.21
Unloading, hauling and delivery along line	1,017.90
Customs charges and duties	460.90
Mexican railroad freight (Douglas to Ysabal)	87.59
	$ 3,376.15
Transmission line — Pins:	
First cost	$ 1,524.18
U. S. freight	326.49
Unloading, hauling and delivery along line	167.03
Custom charges and duties	184.12
Mexican railroad freight (Douglas to Ysabal)	25.26
	$ 2,227.08
Transmission line — Insulators:	
First cost	$ 7,312.99
Inspecting and testing	308.90
U. S. freight	4,046.93
Unloading, hauling and delivery along line	507.48
Assembling and erecting	468.25
Customs charges and duties	1,006.56
Mexican railroad freight (Douglas to Ysabal)	430.11
	$14,081.22
Telephone line — Cross-arms:	
First cost	$ 393.00
U. S. freight	196.08
Unloading, hauling and delivery along line	43.97
Custom charges and duties	167.41
Mexican railroad freight (Douglas to Ysabal)	63.51
	$ 863.97
Telephone line — Cross-arm hardware:	
First cost	$ 240.27
U. S. freight	51.36
Unloading, hauling and delivery along line	16.51
Custom charges and duties	51.60
Mexican railroad freight (Douglas to Ysabal)	6.07
	$ 365.81

Telephone line — Pins:

First cost	$ 130.20
U. S. freight	70.44
Customs charges and duties	4.40
Mexican railroad freight (Douglas to Yshabal)	7.02
	$ 212.06

Telephone line — Insulators:

First cost	$ 525.75
Inspecting and testing	18.90
U. S. freight	216.59
Unloading, hauling and delivery along line	2.58
Customs charges and duties	40.44
Mexican railroad freight (Douglas to Ysabal)	23.57
	$ 827.83

Pole steps, guying and bracing (eyebolts, guy wires, clamps, anchors, pole braces, etc.):

First cost	$ 895.53
Labor	503.00
U. S. freight	138.15
Unloading, hauling and delivery along line	168.00
Customs charges and duties	176.85
Mexican railroad freight (Douglas to Ysabal)	35.78
	$ 1,917.31

Special structures, concrete and cribbing, incident to special construction:

First cost	$ 465.60
Labor	973.10
U. S. freight	52.22
Unloading, hauling and delivery along line	85.00
Customs charges and duties	22.10
Mexican railroad freight (Douglas to Ysabal)	20.63
	$ 1,618.65

Painting:

First cost	$ 313.43
Labor	206.00
Customs, charges and duties	18.61
Mexican railroad freight (Douglas to Ysabal)	0.54
	$ 538.58

Transmission line — Wire:

First cost	$18,096.29
U. S. freight	2,695.78
Unloading, hauling and delivery along line	353.48
Assembling and erecting	2,658.75
Customs charges and duties	1,968.61
Mexican railroad freight (Douglas to Ysabal)	172.90
	$25,945.81

Transmission line — Ties or clamps:

First cost	$ 279.03
U. S. freight	21.38
Unloading, hauling and delivery along line	1.00
Assembling and erecting	7.00
Customs charges and duties	23.26
Mexican railroad freight (Douglas to Ysabal)	20.40
	$ 5,363.05

Telephone line — Wire:	
First cost	$ 3,249.41
U. S. freight	388.54
Unloading, hauling and delivery along line	96.60
Assembling and erecting	1,231.50
Customs charges and duties	365.30
Mexican railroad freight (Douglas to Ysabal)	31.70
	$ 1,795.92
Telephones:	
First cost	$ 1,132.24
U. S. freight	138.22
Unloading, hauling and delivery along line	50.00
Assembling and erecting	401.63
Customs charges and duties	21.82
Mexican railroad freight (Douglas to Ysabal)	52.01
	$ 739.50
Clearing and trimming:	
Right of way, including easements or real estate and collateral costs incident thereto	$ 1,048.96
Pole signs	129.60
Preliminary work, including payments made by Tigre Mining Co. to J. Langston for services and expenses	4,033.75
Contractors' equipment and tool account	1,040.35
First cost	892.83
U. S. freight	70.05
Customs charges and duties	48.53
Mexican railroad freight (Douglas to Ysabal)	19.94
Labor	9.00
Stable — operation and feed	$ 1,373.62
Camp — equipment	817.76
Camp — expenses and repairs	271.00
Subsistence	4,061.57
General engineering and administration (New York)	76.33
General engineering and administration (local office), including surveys	5,476.84
Office	$ 2,436.95
Surveys, including surveys by Tigre company	3,039.89
Traveling expenses and board of general engineers and contractors	597.28
Transportation and expenses incident to placing any labor on job and housing of same	425.89
Medical services and expenses	24.75
Expenses due to insurrection (repairs, etc.)	1,041.57
Trail along transmission line	723.75
Station house on line "fronteras"	62.50
Total "transmission line"	$112,134.99

TABLE XXXII. DOUGLAS SUB-STATION

Excavation, grading, and disposition of excavated material	$ 257.38
Foundations of sub-station building (substructure)	142.77
Machinery foundations	191.74
Building (superstructure)	2,398.66
Brickwork	$ 1,400.00
Labor and material (miscellaneous)	998.66
Switchboard and wiring (thereof, thereto, therefrom)	1,903.05
Switchboard	$ 1,300.00
Freight	49.14
Nyelec panel and switches	47.00
Insulators, fittings, clamps, wire, etc.	365.26
Labor	141,65

Underground cable between switchboard and step-up sub-station		1,583.55
Cable	$ 1,270.01	
Cable terminals and jointing compound	28.41	
Miscellaneous material and cartage	132.99	
Labor	152.14	
Sub-station step-up transformers		8,401.64
Four 400-kva. step-up transformers	6,207.34	
Freight	1,185.30	
Drying transformers	266.00	
Miscellaneous material	21.00	
Labor	722.00	
Painting and finishing of machinery		10.02
Plumbing, lockers, and other sub-station furnishing		35.99
Contractors' equipment and tool account		153.84
Traveling expenses and board of general engineers and contractors		20.80
Transportation and expenses incident to placing any labor on job, and housing of same		93.50
Tests of equipment		948.49
Steam and electric power	745.00	
Miscellaneous material	203.49	
Total Douglas sub-station		$16,141.43

TABLE XXXIII. EL TIGRE SUB-STATION

Sub-station proper		$ 5,294.55
Switchboard and wiring (thereof, thereto, therefrom)		5,362.26
Switchboard	3,780.00	
Freight, customs charges, and duties	769.47	
Nyelec panel and switches	106.00	
Insulators, fittings, clamps, wire, etc.	594.94	
Labor	111.85	
Sub-station step-down transformers		8,899.26
Four 320-kva step-down transformers	4,989.09	
Freight, customs charges, and duties	1,964.24	
Miscellaneous material	531.98	
Labor	1,413.95	
Traveling expenses and board of general engineers and contractors		32.70
Transportation and expenses incident to placing any labor on job, and housing of same		70.00
Tests of equipment		173.58
Total El Tigre sub-station		$19,832.35

TABLE XXXIV. RECAPITULATION OF COSTS

Transmission line	$112,134.99
Douglas sub-station	16,141.43
El Tigre sub-station	19,832.35
Total	$148,108.77
Fees paid Sanderson & Porter	13,000.00
	$151,108.77

(The total shown above, amounting to $161,108.77, includes disbursements made by Sanderson & Porter amounting to $132,743.48, and as reported by the Tigre Mining Co. amounting to $28,365.29.)

The plant in Douglas consists of 2 750-kw. exhaust steam turbo-generators which will work with a 50% underload or overload

without any very serious loss of efficiency. The Tigre Mining company receives power at the bus bars at a tension of 2,200 volts. This is stepped up to 44,000 volts by means of 3 General Electric transformers. At the mine the current is stepped down to 440 volts and distributed to the various circuits in the plant.

The transmission is unusual on account of the small quantity of power being transmitted such a long distance. The current is 44,000 volt, 60 cycle, 3 phase, transmitted over a single line of wooden poles carrying 3 conductors of No. 4 B. & S. gage, medium, hard drawn copper wire with telephone wires below. The poles are 200 ft. apart; at the crossing of the Bavispe River the span is 1,600 ft. The cost of the line from the low tension side of its step-up transformer station at Douglas to the low tension side of its step-down transformer station at El Tigre was $161,121. Not including the transformer stations at each end, their cost was very closely equal to $2,000 per mile. The line, including the transformer stations, was built by Sanderson & Porter of New York. The total cost of the exhaust steam turbo-generator plant including the steam piping, etc., was $71,894, the machinery being installed by the Copper Queen Consolidated Mining Co. During the past year, 6,000 tons of ore have been concentrated monthly and 7,500 tons cyanided at the Tigre mill; an average of 616 h.p. is distributed at El Tigre switchboard. The delivered cost is $86 per h.p. per year; the cost at Douglas being 0.95 per kw.-hr.

Distribution Equipment Cost on a Small System. Electrical World, February 21, 1914, makes the following abstract from a report to the lighting committee of the town of South Hadley, Mass., by Mr. William Plattner, manager of the North Attleboro (Mass.) electric lighting department, in which a thorough study was made of the cost of the local distribution system. The value of the equipment in use was based upon the market price of its replacement, as of August, 1913, and transportation charges, freight and express and the labor cost of installation were included.

ESTIMATED COST OF REPLACING VARIOUS EQUIPMENT

	Poles in place		
Number and kind	Cost	Length, ft.	Expected life, yr.
315 first class, at $3.75	$1,181.25	25	15
63 first class, at $4.50	283.50	30	15
132 second class, at $4.00	528.00	25	10
28 second class, at $4.50	126.00	30	10
94 third class, at $4.00	376.00	25	5
18 third class, at $4.50	81.50	30	5
11 fourth class, at $4.00	44.00	25	Need
1 fourth class, at $4.50	4.50	30	replacement

Painting 129 poles at $0.50	$64.50
Setting 71 poles in concrete, at 0.50	35.50
Setting 4 poles in curb, at 0.50	2.00
Fourteen guys.— 80 ft. No. 4 copper wire, 299 ft No. 6 copper wire, and 444 ft. No. 6 galvanized steel wire, all in place	85.75

ELECTRIC METERS (G. E. TWO-WIRE)

No.	Size, amp.	Unit cost	Total cost	Transportation	Labor, erection	Total	Total per meter
40	5	$10.00	$400.00	$13.00	$20.00	$433.00	$10.82
267	10	11.20	2990.48	81.25	135.00	3206.73	12.00
17	15	12.80	217.60	5.00	10.00	232.60	13.65
31	25	16.00	496.00	9.50	16.00	521.50	16.80
11	50	21.40	235.40	3.67	8.00	247.07	22.36
2	100	26.70	53.40	1.00	5.00	59.40	29.70

TRANSFORMERS (G. E. AND STANLEY, VOLTAGE 1100–2200; 110–220)

No.	Size, kw.	Unit cost	Total cost	Freight charges	Labor, erection	Total	Total per transformer
65	1	$21.80	$1417.00	$23.90	$96.00	$1536.90	$23.60
16	1.5	26.00	416.00	4.00	24.00	444.00	27.80
21	2	30.40	638.00	10.40	30.00	678.40	32.20
9	2.5	34.00	306.00	5.00	18.00	329.00	36.60
10	3	38.00	380.00	5.00	19.00	404.00	40.40
2	4	45.60	91.20	2.90	5.00	99.10	49.55
9	5	53.20	478.80	9.20	18.00	506.00	56.22
2	7.5	70.40	140.80	2.68	10.00	153.48	76.74
3	10	87.20	261.60	3.80	20.00	285.40	95.13
1	20	146.80	146.80	2.74	18.00	167.54	167.54
1	25	172.80	172.80	4.00	18.00	194.80	194.80
1	30	197.20	197.20	5.50	22.00	224.70	224.70

The transformer costs include fuses, cut-outs, hangers and oil.

TRANSFORMER HOUSE, SOUTH HADLEY

One house, matched boards, 7 ft. 3 in. by 7 ft. 3 in. by 9 ft. 9 in. high in front, 8 ft. 6 in. high in rear, tar-paper roof, paneled window, wire screen door, painted	$ 75.00
One G. E. regulator, type I.R.S., 8.75 kva., 2300 volts, 25 amp., complete with panel and transformers	468.40
One G. E. constant-current transformer, 10 kw., 5.5 amp., form G, complete	304.50
One G. E. transformer, 1 kw., oil type, 2200 volts to 110-220 volts	16.73
One Campbell time switch, series street lighting, 2500 volts, two-pole, 25 amp., eight-day clock	25.00
Two G. E. 2300-3000-volt horn-gap lightning arresters	9.50
Inside wiring, material, labor, etc.	35.50
Outside wiring including 300 ft. service for lighting	21.75
Total	$956.38

Cost of Additions and Improvements to Central Stations. The following data were given in Electrical World, Aug. 16, 1913. A 2000-kw. Curtis steam turbine costing about $30,000 has been installed in the main steam plant by the Greenfield (Mass.) Electric Light & Power Co., with two Porcupine boilers, rated at 500 h.p. each, at a cost of $11,500. The condensing-water supply formerly pumped into the station has been rearranged to permit its introduction by gravity.

New equipment of the Gardners Falls station of the New England Power Co. includes two 1,450-h.p. turbines designed to operate at 150 rev. per min. under 37 ft. working head and an exciter turbine of S. Morgan Smith make, rated at 135-h.p., the cost of

these erected being $11,500, or $3.85 per h.p. The electrical apparatus consists of 2 generators of 1170 kva. rating, a 60-kw. exciter and three 1200-kva., 3-phase transformers for delivering energy at 13,200 volts to the Greenfield company's transmission feeders, the price of this equipment f.o.b. factor being $29,500. The estimated cost of switchboard additions for this installation is about $15,000, including incidentals, and the contract for excavation, extending the station and installing foundations is figured at $4,250.

Central Station Equipment Costs. Electrical World, April 28, 1917. Improvements on the system of the Fitchburg (Mass.) Gas & Electric Light Company (1916) included the installation of a 2500-kw. high-pressure Westinghouse turbine with LeBlanc condenser and foundations, centrifugal feed pump, piping, superheaters, 2 500-h.p. Bigelow-Hornsby water-tube boilers, 2 Taylor stokers, feed-water meter, air compressor, pipe covering, coal-handling equipment, economizers, mechanical draft apparatus and a 1,000-h.p. feed-water heater. To house the additional equipment the plant was extended about 36 ft. From the cost sheets of the company the following items are printed to give engineers a general idea of the relative unit costs of equipment in a plant of this size:

2500-kw. Westinghouse double-flow turbine (not including generator), with No. 14 LeBlanc condenser, complete with pumps	$19,779.40
Turbine foundations	2,221.76
300-gal.-per-min. Westinghouse centrifugal boiler-feed pump	1,545.00
Connecting turbine and condenser	472.86
Galvanized-iron air duct for turbine	236.00
Type C duplex piston automatic pump and receiver	125.40
Miscellaneous items, completed December, 1914	973.43
1 5-in. and 2 6-in. Edwards check valves	318.68
Installation of above	114.30
New superheater for 240-hp. Stirling boiler	675.00
Piping, covering and brickwork for above	228.69
Freight, teaming, insurance and miscellaneous	111.94
2 500-hp. Bigelow-Hornsby water-tube boilers	9,000.00
Masonry in connection with above	1,316.94
Foundations	4,206.67
2 Foster superheaters	2,900.00
2 feed-water controllers	160.00
Labor Fitchburg company's force	418,19
Pipe covering	167.95
Miscellaneous	1,073.59
Labor and material installing floor grates	57.57
(Note.— Total additions to boilers, $20,782.34).	
2 Taylor stokers, grates, fans, engine and driving mechanism	9,785.00
Foundations for above (paid contractor)	704.13
Crushed stone, sand, etc., for foundation	165.00
Steel for coal hoppers	329.41
Labor for coal hoppers	157.20
Shafting, hangers, chains, etc.	301.00
5-in. by 5-in. vertical stoker engine	248.00
Labor, Fitchburg company's force	592.49
Other items	711.87
4 sheet-steel boxes for stokers in ash pit	48.00
Labor and material installing above boxes	30.33
(Note.— Total additions on account of stoker cost, $13,072.43)	

4-in. type M. Venturi registering and indicating feed-water meter	465.00
Freight, teaming and installation of above	46.02
Piping installation, in connection with station increase	16,028.66
Coal-handling apparatus	4,967.10
1000-hp Whitlock feed-water heater	575.00
Sturtevant economizer installation for additional capacity of plant	12,423.14
5-hp. motor and wiring for above	73.75
3125-kva. 60-cycle, 3-phase, 2300-volt generator	9,879.60
Other labor and material	571.92
3 sheet-steel guards for generator flywheels (old units)	60.00
75-kw. motor-generator exciter set, 115-hp. 220-volt motor	1,758.00
2 2500-volt aluminum lightning arresters	234.00
6 300-amp. 250-volt single-pole switches	29.70

The total cost of the complete improvements outlined is not obtainable by adding items segregated herewith, since the data presented includes merely items of broad interest.

Plant Extensions at Amesbury, Mass. The following is taken from Electrical World, Sept. 13, 1913. The Amesbury Electric Light Company in increasing the capacity of its generating plant by the addition of a 1000-kw. steam-turbine unit with the necessary boiler capacity, condensing equipment and auxiliary apparatus, estimated the cost of the new work, based on bids received and previous experience in the enlargement of the plant, as follows:

ESTIMATED COST OF ENLARGING STATION AT AMESBURY, MASS., 1913, BY 1000 KW.

Extension of power plant building	$ 9,122
Kellogg radial brick stack; height, 150 ft.; diam. at top, 6 ft.	3,585
Stack foundation	840
Piling, excavation, etc.	400
Turbine foundation, 10 ft. by 20 ft. by 14 ft.	1,200
Boiler foundation, 19 ft. by 26 ft. by 11 ft.	1,300
Excavation for suction piping, 2000 cu. yds. at 50 cts.	1,000
2 400-hp. water-tube boilers, Babcock & Wilcox	9,781
Brickwork	1,500
2 superheaters	2,214
2 Taylor stokers	6,150
Boiler flue	800
Coal-handling cars and track	1,200
1000-kw. horizontal Curtis turbine, 60 cycles, 2300 volts	13,200
Westinghouse Le Blanc No. 8 condenser, capacity 20,500 lbs. steam per hr. 28 in. vacuum turbo pumps, 70 degs. water	3,225
Piping	3,000
Feed pumps, heater, etc.	800
Pipe covering	1,000
Turbo-alternator switchboard	500
Erecting and wiring board and turbine	500
Incidentals, 10%	6,132
Total	$67,449

Cost of Control Apparatus for 19,000-volt Power Station. Electrical World, July 17, 1915, gives the following cost of switches, lightning arrestors and other apparatus in the Vernon power-station end of the Vernon Station-Massachusetts line as follows:

2 150-amp., 70,000-volt, triple-pole, single-throw, sole-noid-operated oil switches, complete	$ 2,093.00
12 100-amp. disconnecting switches, complete	408.30
6 300-amp., 70,000-volt disconnecting switches, at $27.90	167.40
2 70,000-volt aluminum lightning arresters, complete with supports, tanks, fittings, etc., at $765	1,530.00
1 20,000-volt aluminum-cell lightning arrester	360.00
3 single-pole, time-limit series relays, with switches, operating rods, bases and insulators, at $60	180.00
6 single-pole, time-limit 100-amp., 22,000-volt disconnecting switches with 10-in. base	81.00
Steel frame for extending monitor, 48 ft and one 24 ft	440.00
Structural steel for 2 roof frames, 4 stubs and 6 brackets	222.00
3 300-amp., 70,000-volt disconnecting switches, at $34.20	102.60
2 600-volt, dc. aluminum lightning arresters for telephone system, at $9	18.00
3 type H 60-cycle, 5000-watt, 2400/240-volt secondary transformers, form K	195.52
Set cores and coils	27.00
3 single-pole, single-throw, 100-amp., 22,000-volt disconnecting switches	18.00
15 knife switches, 3¾ ins. wide	40.30
Insulators, pins and supports	463.29
Pipe and pipe fittings	619.50
Miscellaneous switching apparatus	162.00
Tools, etc.	389.60
Hardware	188.48
Miscellaneous materials, oil drums, etc.	201.30
Transportation of material	370.72
Labor and expenses	3,229.09
Total	$11,507.10

Cost per Pound of Electrical Machinery. Leonard A. Doggett in Electrical World, Oct. 2, 1915. gives the figures below based upon data collected from various sources.

It is a well-known fact that a 1-h.p. motor having a rated speed of 2000 rev. per min. is much cheaper than, and about .5 as heavy as, a 1-h.p. motor having a rated speed of 1000 rev. per min. Therefore, the rational way to tabulate either cost or weight data is in terms, not of dollars or lbs. per kw., but of dollars or pounds versus kilowatts divided by speed. The term (kw.÷ rev. per min.) is really torque, and of any machine it can be said that the greater the torque the greater the necessary size, weight and cost. Therefore, in this paper the independent variable is taken as (kw. ÷ rev. per min.). In Figs. 13 and 14 the accumulated data are plotted,

TABLE XXXV. COSTS AND WEIGHTS OF ELECTRICAL MACHINERY

Name of machine	New or second-hand	Kw. ÷ rev. per min. 0.001	0.01	0.1	1.0	10.0
Direct-current generators and motors..	New	85	280	1,150	5,500	......
Induction motors.....	New	100	260	850	3,500	......
Alternators	New	...	...	1,200	4,600	16,000
Turbo-alternators ...	New	...	...	....	37,000	136,000
Low-speed engines...	New	Compound		....	6,000	17,700
High-speed engines...	New	Compound		1,600	4,900	......
Low-speed engines...	New	Simple		....	3,200	13,500
High-speed engines...	New	Simple		680	2,530	......

COSTS IN DOLLARS

Name of machine	New or second-hand	Kw. ÷ rev. per min. 0.001	0.01	0.1	1.0	10.0
Direct-current generators and motors..	Second-hand	40	120	450	1,600	......
Induction motors....	Second-hand	45	170	550	2,500	......
Alternators	Second-hand	..	140	450	2,200	8,000
Engine-driven direct current and alternating-current generators	Second-hand	..	200	700	3,000	13,000

WEIGHT IN POUNDS

Name of machine	New or second-hand	0.001	0.01	0.1	1.0	10.0
Direct-current generators and motors..	....	130	810	4,200	22,000	110,000
Induction motors....	....	80	510	2,800	15,000	81,000
Alternators	....	130	810	4,200	20,000	90,000
Turbo-alternators ...	....	...	...	....	170,000	640,000
Low-speed engines...	....	...	...	2,400	19,000	140,000
High-speed engines..	....	...	...	4,500	31,000	......
Engine-driven direct current and alternating-current generators	....	...	1,400	8,000	50,000	250,000

CENTS PER POUND

Name of machine	New or second-hand	0.001	0.01	0.1	1.0	10.0
Direct-current generators and motors..	New	65	35	27	25	......
Induction motors....	New	125	51	30	23	......
Alternators	New	...	...	29	23	18
Turbo-alternators ...	New	...	...	...	22	21
Low-speed engines...	New	Compound		...	28	11
High-speed engines...	New	Compound		36	15	......
Low-speed engines....	New	Simple		...	17	9
High-peed engines....	New	Simple		15	8	......
Direct-current generators and motors..	Second-hand	31	15	11	7	......
Induction motors.....	Second-hand	56	33	20	17	......
Alternators	Second-hand	...	17	11	11	9
Engine-driven direct-current and alternating-current generators	Second-hand	..	14	9	6	5

In using Figs. 13 and 14 it should be remembered in the case of new machinery that these figures represent standard or stock machines, and that machines with unusual specifications will lie above any data there plotted.

In gathering and plotting the information interesting facts developed, many of which could be explained. For example, cost figures on Edison bipolars, Stanley inductor alternators and 133-cycle alternators, if they had been plotted, would always have fallen below the general trend of the plotted points. That is, obsolete types of machines lie between the curve for second-hand machines and the scrap value of the machine. In Fig. 13 are plotted some data on new 1-hr. rating series motors, these points being represented by #. As would be expected, these points lie between the points for new and those for second-hand direct-current machines.

It is interesting to note that the average cost of all the new machinery tabulated is 32 cts. per lb., and of the second-hand machinery 17 cts. per lb.

Miscellaneous Central-Station Construction-Cost Data. Electrical World, Sept. 27, 1913. In connection with the completion of

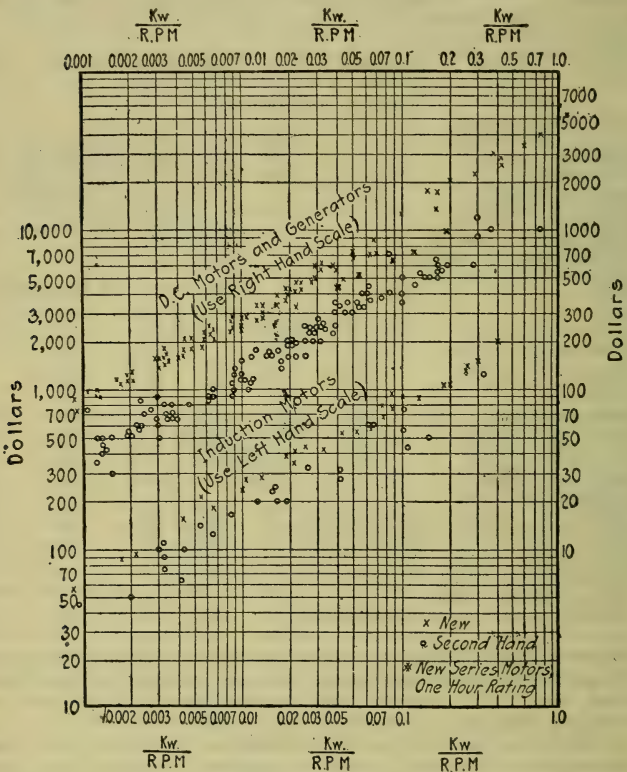


Fig. 13. Charts plotting cost data for electrical machinery.

recent improvements in the plants and systems of several of the Tenney central-station companies in Massachusetts, the following cost data have been obtained. The companies drawn upon are the Haverhill Electric Company, Malden Electric Company, Fitchburg Gas & Electric Company and Suburban Gas & Electric Company of Revere.

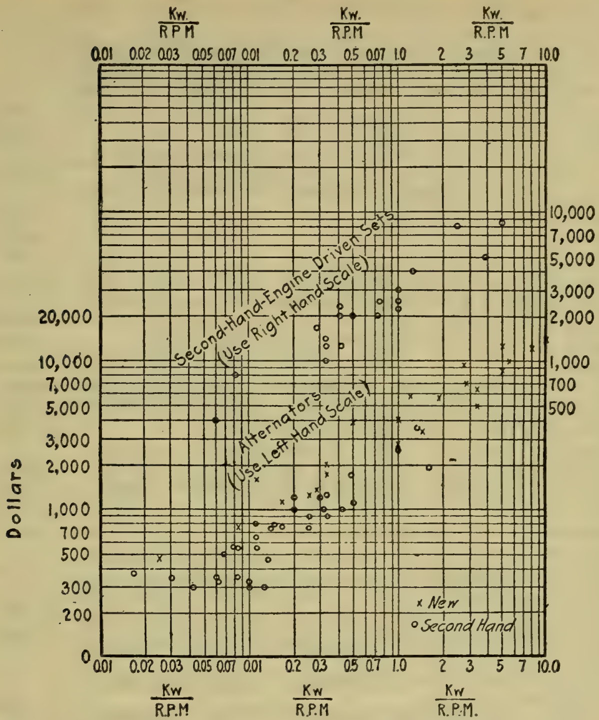


Fig. 14. Charts plotting cost data for electrical machinery.

Sea Wall for Haverhill Station, on Merrimac River.

Granite wall, rough cut stone, backfilled with earth filling; length, 410 ft; width, 14 ft to 18 ft; height, 25 ft; area, 6329 sq ft. Cost of material and labor, $17,500; miscellaneous, $1,215; total.............. $18,715.00

Stock House Vault, Haverhill.

Built of brick, two stories, 8 ft by 10 ft inside dimensions, 8-in outer wall, 2-in air space and 8-in inner wall. Cost, $580; doors, wiring, shelves, etc., $350.-08; total cost 930.08

New Generating Unit, Haverhill.

One 25-kw steam turbine arranged for direct connection and mounted on common bedplate, including one No. 16 Westinghouse LeBlanc condenser and electric generator; erected complete, Westinghouse Machine Company 31,639.00

Miscellaneous Steam and Electric Plant Equipment, Haverhill.

One 9-in. by 12-in. by 10-in. duplex piston-pattern pump, brass-lined pump cylinders, Tobin bronze piston rods, composition pump pistons, brass valve seats, medium-hard rubber valves for cold water and high lift	405.00
Foundation, pipe connections, etc.	401.39
One Sarco CO_2 recorder	326.80
One 6-ft. by 21½-ft. Scannell return tubular boiler removed from service; first cost complete, erected	2,607.30
One 3125-kva., 60-cycle, 3-phase, 2300-volt Westinghouse turbo-generator	9,227.87
Switchboard apparatus	955.38
Cable	248.52
Air duct	408.80
4 60-lamp, 60-cycle, 220-volt, 2.75-amp. air-cooled, constant-current transformers	1,040.00
4 series arc oil switches, 9E, type F, form 2, 2.10 amp., 1200 volts	224.00
10 25-ft. ornamental arc-lamp poles ($38 each)	380.00
68 30-ft. chestnut poles, painted and shaved, at $5.56	377.86
140 35-ft. chestnut poles, painted and shaved at $7.55	1,054.14
19 40-ft. chestnut poles, painted and shaved at $8.75.	166.80
1 50-ft. chestnut pole, painted and shaved	10.50
1 60-ft. chestnut pole, painted and shaved	18.75
15,820 ft. (6252 lb.) No. 0, triple-braided, weatherproof, solid wire, at 14.2 cts. per lb.	889.22
1 30-in. Lumsden & Van Stone steam-exhaust head	189.00
1 16-in. Standard twin strainer, No. 684	428.63

Transformers, All 60-Cycle Equipment.

19 1-kw. 2200-1100-volt primary, 220-110-volt secondary, single phase, each	17.06
8 1½-kw. 2200-1100-volt primary, 220-110-volt secondary, single-phase, each	23.13
27 2½-kw. 2200-1100-volt primary, 220-110-volt secondary, single-phase, each	30 68
30 5-kw. 2200-1100-volt primary, 220-110-volt secondary, single-phase, each	49.43
6 7½-kw. 2200-1100-volt primary, 220-volt secondary, single-phase, each	65.17
6 10-kw. 2200-1100-volt primary, 575-volt secondary, single-phase, each	80.95
3 15-kw. 2200-1100-volt primary, 575-volt secondary, single-phase, each	110.67
1 20-kw., 2200-1100-volt primary, 575-volt secondary, single-phase, each	137.14
3 25-kw. 2200-kw.-1100-volt primary, 575-volt secondary, single-phase, each	$172.86
6 30-kw., 2200-1100 volt primary, 575-volt secondary, single-phase, each	183.82
3 50-kw. 2200-1100-volt primary, 575-volt secondary, single-phase, each	252.70
1 50-kw., 2200-1100-volt primary, 220-volt secondary, single-phase, subway type, each	310.88

Meters.

67 5-amp., 110-volt Fort Wayne type "K3," each	$9.28
546 10-amp., 110-volt Fort Wayne type "K3," each	10.06
5 15-amp., 110-volt Fort Wayne type "K3," each	13.00
33 25-amp., 110-volt Fort Wayne type "K3," each	13.00
21 50-amp., 110-volt Fort Wayne type "K3," each	18.68
1 300-amp., 110-volt Fort Wayne type "K3," each	27.00
2 400-amp., 110-volt Fort Wayne type "K3," each	27.40

20 5-amp., 550-volt, Fort Wayne type "K3," each....	27.40
16 10-amp., 550-volt Fort Wayne type "K3," each....	33.83
3 15-amp, 550-volt Fort Wayne type "K3," each....	34.80
13 25-amp., 550-volt Fort Wayne type "K3," each....	35.84
6 50-amp., 550-volt Fort Wayne type "K3," each....	39.60
1 150-amp., 550-volt Fort Wayne type "K3," each....	66.26
1 200-amp., 550-volt Fort Wayne type "K3," each....	51.60
9 15-amp., Wright demand meters, each............	5.78
6 75-amp., Wright demand meters, each	7.80

Power-Plant Equipment, Fitchburg.

5 6-in. G. E. steam-flow meters, type "Ts 2," 200 lbs., at $48 each	$240.00
Labor of installing above	24.19
Pipe, fittings and material	31.77
Total ($59.19 per meter)	$295.96
3 2-in. Squires feed water regulators, at $90 each....	$270.00
Labor of installation	44.38
Miscellaneous material, gate valves, pipe, etc........	38.37
Total ($117.58 per regulator)	$352.75
2 Murphy automatic smokeless furnaces	$2,868.00
Installation of above	212.21
1 5-hp. 50-volt motor	190.25
Miscellaneous material and labor, oil pan, steel spur, etc.	52.28
Total ($1,661.37 per stoker)	$3,322.74
1 13-ft. by 5-ft. straight-blade Sturtevant exhaust fan with engine	$7,220.00
Piping for above	664.74
Labor and material	1,782.83
Total cost of fan installed	$9,667.57
1 Sturtevant economizer, 360 tubes, 10 ft. long. Total heating surface, 4903 sq. ft.	$5,240.00
Foundation	450.00
1 5-hp. motor, including labor	262.00
Miscellaneous material, including pipe, fittings, etc....	1,418.94
Total ($1.50 per sq. ft. heating space)..........	$7,370.94

Ornamental Street-Lighting Fixtures, Fitchburg.

93 fixtures, each equipped with 4 60-cp, 6.6-amp series incandescent lamps, connected to underground arc system through 1-to-1 transformers and mounted on local street-railway feeder poles	$1,860.00
Labor of installation	1,088.67
Cable and wire	1,838.61
Miscellaneous material, cross-arms, cut-outs, pipes, etc.	1,419.58
Total ($66.50 per fixture)	$6,206.86

Malden Plant Equipment.

1 steel structure, forced-draft cooling tower, 2000-kw. capacity, complete with foundations	$14,531.47
1 Parsons ash ejector, installed, with 16-ton ash tank	2,173.22
4 Kibbs safety feed-water regulators with 2½-in. valve	340.00
Cost of installing above regulators	103.95
1 5-amp., 3-phase, 115-volt wattmeter	56.60
1 3-phase G. E. electrostatic ground detector........	115.51
3 500-kw., indoor-type, oil-cooled 13,200-volt transformers	4,325.00
1 15,000-volt aluminum lightning arrester	477.75
400-ft. 400,000-cir. mil. flame-proof cable for 5000 volts	158.70

Malden Underground Construction Costs.

27,395 ft. 2½-in. fiber conduit	$923.67
100,830 ft. 3½-in. fiber conduit	4,394.21
Cost of installing above by contract	48,297.06
Total cost of conduit	$53,614.94

Line to Revere.

26,896 ft. No. 00, 3-conductor cable for 17,000 volts	$28,040.80
Installation, contract at 4.5 cts. per ft.	1,210.32
Total cost to Revere line	$29,241.12

Cable Installation in Malden.

22,721.5 ft. No. 00 cable	$12,240.31
31,497.5 ft. No. 0 cable	16,294.42
93,519 ft. No. 6 cable	17,095.27
Cost of drawing in above 147,768 ft. cable	3,859.44
25 G. & W. potheads	709.82
Labor, company's employees	519.20
Miscellaneous items, freight, tape, asbestos cloth, etc.	5,283.46
Total	$56,001.92
Liability insurance, miscellaneous materials, labor of employees, etc., on general work	3,865.30
Total additions to underground system	142,723.28

Miscellaneous Items, Malden System.

Driving 106 ft. 2.5-in. galvanized-iron pipe for cable grounding, at contract rate of $1.75 per ft.	$189.14
Company labor and material, including cost of pipe	85.12
Total	$274.26

Revere, Miscellaneous Costs.

One 68-ft. by 58-ft. one-story cement and brick, steel-trussed garage: building, $5,300; trusses, $566; miscellaneous, $1,413.03 (including labor, $348.91)	$7,279.03
(Included in above one 40-gal. chemical extinguisher on wheels, $144).	
40,000 ft. duct; 3½-in-1½ in. socket joint conduit	1,895.25
Thirty manholes	572.50
Nineteen 500 watt sign-lighting transformers, at $10.67 each	202.67

TABLE XXXVI. ARRESTERS, LIGHTNING

DIRECT CURRENT STATION TYPE

Voltage	Weight, lb.	Price
0– 350	2¾	$3.20
350– 750	4½	3.50
750–1300	11½	7.00
1300–1500	11½	8.00
1500–1800	11½	8.50
0–4000 *a*	6¾	4.40
4000–6000 *a*	20	11.00

a = arc. circuits.

ALTERNATING CURRENT STATION TYPE

Voltage	Weight, lb.	Price
0– 350	2¾	$3.20
350– 1200	4¾	3.50
1200– 2500	6¾	4.40

Voltage	Weight, lb.	Price
2500– 3500	11½	5.00
3500– 5000	26½	11.00
5000– 6600	41	11.50
6600– 7500	46	18.20
7500– 8500	58	19.55
8500–10000	71	24.30
12500–15000	106	36.95
15000–17500	123	44.50
17500–20000	140	50.00

FOR THREE-PHASE CIRCUITS

Voltages	Weight, lb.	Price
5700– 7600	353	$85.00
7600–11250	465	137.00
11250–13500	550	172.50
13500–17000	650	210.00
17000–22000	805	250.00
22000–27000	980	330.00
27000–32000	1245	420.00
32000–37000	1430	500.00

FOR SINGLE-PHASE CIRCUITS

Voltages	Weight, lb.	Price
5700– 7600	265	$60.00
7600–11250	350	92.50
11250–13500	415	115.00
13500–17000	490	147.50

TABLE XXXVII. DIMENSIONS, WEIGHTS AND RATED PERFORMANCE OF EDISON CELLS

Size of cell	Over-all dimensions of cell, in.			Weight in lb.		Normal rate of charge and discharge, amperes	Rated capacity		Watt-hours per lb. of cell for rated capacity	Average watts during discharge at normal rate
	Length	Width	Height	Complete cell	Av. per cell with trays, etc.		Ampere-hours	Watt-hours		
B– 2	1.5	5.1	8.8	4.6	5.5	8	40	48	10.4	9.6
– 4	2.6	5.1	8.8	7.4	8.7	16	80	96	13.0	19.2
– 6	3.8	5.1	8.8	11.0	12.0	22.5	112.5	135	13.7	27
A– 4	2.7	5.1	13.4	13.3	14.5	30	150	180	13.3	36
– 5	3.2	5.1	13.4	16.8	18.5	37.5	187.5	225	13.4	45
– 6	3.8	5.1	13.4	19.0	21.0	45	225	270	14.1	54
– 8	5.0	5.3	14.0	27.0	30.0	60	300	360	13.1	72
–10	6.2	5.5	14.0	34.0	37.5	75	375	450	13.2	90
–12	7.4	5.5	14.6	41.0	45.0	90	450	540	13.2	108

Table XXXVII is from the American Handbook for Electrical Engineers.

The Edison Storage battery, best-known of the alkaline types, was first used commercially in 1904. The elements consist of nickel hydroxide for the active material of the positive plate and iron for the active material of the negative plate. Dilute potassium hydrate solution is used as the electrolyte.

Cost of Edison cells complete including trays, etc., is approximately $1.00 per pound.

Storage Batteries For Isolated Lighting Plants. For 110 volt lamps, 62 cells will usually be found satisfactory if the battery is not too far from the center of distribution of the lights. With this number of cells, the voltage may fall one or two volts below 110 at the end of a complete discharge at the normal (8 hr.) rate, or a little lower at higher rates of discharge; but on the few occasions when a complete discharge is required, this final drop of pressure will not, ordinarily, be objectionable. If the requirements are still less exacting, 60 cells might prove satisfactory. If no drop in voltage is permissible, 64 cells would be necessary for 110 volt lamps, or even a greater number if the drop in voltage in the wiring is appreciable.

The amp.-hr. capacity of a battery decreases as the rate of discharge increases. The "normal" rate of discharge is the 8 hr. rate; the "normal" capacity is the amp. hrs. obtained at the "normal" or 8 hr. rate of discharge. At rates of discharge greater than the normal or 8 hr. rate, the capacity of a battery in amp.-hrs. is, therefore, somewhat less than the normal capacity, this reduction in capacity being practically the same, whether the entire discharge has been effected at the higher rate or the rate is increased after a partial discharge at lower rate. Thus, if a battery has a capacity of 5 amps. for 8 hrs., or 40 amp.-hrs., it can discharge at the rate of 10 amps. for only 3 hrs., or 30 amp.-hrs.; and if, after full charge it be discharged at the rate of 5 amps. for 4 hrs., or 20 amp.-hrs., and the rate of discharge be then increased to 10 amps., it will give this output for 1 hr. longer, thus giving a total of only 30 amp.-hrs., whereas, if the rate had not been increased, the discharge could have been continued at 5 amps. for 4 hrs. longer.

The final voltage at the end of discharge at the 8 hr. rate is about 1.75 volts per cell. At the 3 hr. discharge rate, the voltage will fall to about 1.7 per cell, while during charge the voltage rises from about 2.15 per cell at the beginning to about 2.6 at the end.

TABLE XXXVIII. COST OF STORAGE BATTERIES

(60 cells, 110 volts, parallel charge, series discharge and resistance regulation for 8-hr. discharge)

Capacity, amp.	Shipping weight, lb.	Price complete *
2.5	2,100	$ 175
5.8	3,300	265
7.5	4,300	345
10	5,300	416
12.5	6,200	430
15	6,200	500
20	7,700	600
25	9,800	760
30	10,800	900
35	12,500	1,100
40	18,700	1,280
50	20,200	1,560

Capacity, amp.	Shipping weight, lb.	Price complete *
60	24,000	1,800
70	27,300	2,100
80	34,000	2,400
90	39,000	2,750
100	41,000	3,000

* The above prices include the following material to make up battery complete.

60 elements.
62 glass jars.
60 sand trays.
70 bolt connectors.
245 glass insulators.
62 glass covers.
Necessary electrolyte.
3 Hydrometers.
1 set cell numbers.
1 pair socket wrenches.
1 low-reading voltmeter.
18 terminal lugs.
1 set stringers.

Bus Bar Copper can be obtained in a great variety of sections to fulfill the requirements of the station. Varying from a strap, .05 by .5 in., which on a basis of 1,000 amps. per sq. in. cross section would have a capacity of about 25 amps., to large bars 1 by 3 ins. or larger.

In ordering bus bar copper, 6 ft. is considered the standard length for strips thinner than .09375 in.; 12 ft. for all other.

The following prices are based on such standards, and the price of 15 cts. per lb. for bar copper base. For orders of less than 10 lbs. the price for bus bars is 33 cts. per lb., with a differential for finished bus bars of 2.5 cts. per lb. for each cent increase or decrease, above or below the 15 ct. base price.

In orders of from 10 to 50 lbs. the price of bus bar is 27.5 cts. per lb. with a 2.25 ct. differential for each cent variation in price of base copper.

Bus Bar Aluminum. The average price of stranded aluminum wire f. o. b. factory for the three years ending June 30, 1915, was 25.7 cents, to which should be added 5 cents for installing, giving a price in place of 30.8 cents.

Aluminum Wire. Average price per pound of bare aluminum cable f. o. b. factor for 3 year period immediately preceding the war was 26 cents per pound. The price for weatherproof cable was 20 cents.

Average Price of Ingot Copper. These prices of Lake copper from 1885 to 1898 inclusive and electrolytic copper from 1899 to 1914 inclusive, are quoted from Mineral Industry.

TABLE XXXIX. AVERAGE PRICE OF INGOT COPPER

Year	One-year average	8-yr. average	16-yr. average
1885	11.12	....	....
1886	11.00	....	....
1887	11.25	....	....
1888	16.66	13.00	....

Year	One-year average	8-yr. average	16-yr. average
1889	13.75	12.94	....
1890	15.75	12.76	....
1891	12.87	12.70	....
1892	11.30	11.87	12.63
1893	10.78	11.67	12.84
1894	9.56	11.20	12.98
1895	10.76	11.58	13.10
1896	10.88	12.26	12.86
1897	11.29	12.93	12.98
1898	12.03	13.19	13.20
1899	16.67	13.50	13.65
1900	16.18	13.75	13.75
1901	16.11	14.28	13.89
1902	11.63	15.19	14.09
1903	13.24	15.61	14.18
1904	12.82	15.23	14.54
1905	15.59	14.84	14.78
1906	19.28	14.98	14.88
1907	20.00	14.87	....
1908	13.21	15.32	....
1909	12.88	15.28	....
1910	12.74	14.57	....
1911	12.38	....	....
1912	15.34	....	....
1913	15.27	....	....
1914	13.60	....	....

TABLE XL. COST OF CHOKE COILS FOR CIRCUITS

Capacity, amp.	Weight, lb.	Price
10	4	$ 1.80
20	4	2.40
30	4	2.88
40	4	3.35
50	9.25	4.00
100	9.25	4.25
125	9.25	4.50
175	16.25	5.00
225	16.25	5.25
260	16.25	5.50
50	8.5	4.95
125	8.5	5.50
160	11.0	5.75
200	11.5	5.95
250	12.25	6.05
325	15.5	6.60
400	18.75	9.35
500	21.25	13.25
600	33.75	14.85
800	37.75	17.60
1000	48.75	24.75
1200	65.5	27.50
1500	72.	33.55
1600	89.75	37.40
2000	102.	52.80

TABLE XLI. COST OF MOTOR-DRIVEN EXCITERS

Size, kw.	Weight, lb.	Price f.o.b. factory
	1800 REV. PER MIN.	
2.5	630	$ 220
5.	1,130	365

Size, kw.	Weight, lb.	Price f.o.b. factory
7.5	1,480	460
10	1,800	535
15	2,350	675
20	2,850	800
25	3,300	900
50	6,950	1,650
1200 REV. PER MIN.		
2.5	930	$ 310
5	1,480	460
7.5	1,940	575
10	2,350	675
15	3,050	850
20	3,700	990
25	4,300	1,120
50	6,850	1,650
720 REV. PER MIN.		
10	3,300	$ 900
15	4,300	1,120
20	5,200	1,325
25	6,000	1,500
50	9,600	2,100
75	12,300	2,450
100	15,000	2,700

TABLE XLII. COST OF MOTOR-GENERATOR SETS

1200 REV. PER MIN.

Size, kw.	Weight, lb.	Price f.o.b. factory
100	11,000	$2,000
125	13,000	2,300
150	14,500	2,550
200	17,500	3,050
720 REV. PER MIN.		
200	25,000	$4,200
250	29,500	4,900
300	33,400	5,500
350	37,000	6,000
400	40,800	6,500
450	44,200	7,000
500	47,500	7,400
500 REV. PER MIN.		
200	32,500	$5,300
250	38,000	6,100
300	43,000	6,800
350	48,000	7,500
400	52,500	8,200
450	57,000	8,800
500	61,500	9,400
600	69,500	10,500
700	77,500	11,500
800	85,000	12,500
900	92,000	13,500
1,000	100,000	14,400
360 REV. PER MIN.		
1,000	125,000	$17,800
1,250	145,000	20,400
1,500	163,000	22,800

Weights and Costs of Generators and Turbo-Generators. Tables XLIII and XLIV give weights and prices averaged from a mass of data which we have accumulated in our appraisal work. The prices and weights include the cost and weight of the necessary exciter. There is a variation of about 25% both greater and less than the average in weights and prices of machines of intermediate sizes and a variation of about 35% both greater and less for machines of the smaller and larger sizes listed.

In general, belt-driven machines weigh and cost more than the direct-connected engine, or water-wheel-driven type.

We have given the prices and weights for different sizes of alternators for various revolutions per minute without specifying the electrical characteristics, as it appears that the latter are of minor importance in determining the cost as compared with the speed.

TABLE XLIII. COST OF DIRECT CURRENT GENERATORS

Size, kw.	Weight, lb.	Price f.o.b. factory
	100 REV. PER MIN.	
300	74,000	$8,900
350	80,000	9,700
400	84,000	10,300
450	89,000	11,000
500	91,000	11,500
750	98,000	13,300
1,000	111,000	14,500
	300 REV. PER MIN.	
5	1,830	$350
7.5	2,450	445
10	3,000	520
15	4,050	660
20	5,000	785
25	5,850	900
50	9,700	1,400
75	13,000	1,840
100	16,000	2,200
150	21,500	2,875
200	28,300	3,450
250	31,000	4,000
300	35,500	4,500
350	40,000	5,000
400	44,000	5,450
450	48,000	5,850
500	51,500	6,250
	500 REV. PER MIN.	
1	400	115
2	650	160
3	860	195
4	1,060	230
5	1,250	260
7.5	1,700	325
10	2,100	390
15	2,800	495
20	3,450	580
25	4,050	750
50	6,600	1,000
75	9,000	1,310

Size, kw.	Weight, lb.	Price f.o.b. factory
100	11,000	1,600
150	15,000	2,100
200	18,300	2,500
250	21,500	2,860
300	24,500	3,250
350	27,400	3,600
400	30,300	3,900
450	33,000	4,200
500	35,500	4,500
	1200 REV. PER MIN.	
1	245	$76
2	360	105
3	470	128
4	570	145
5	670	162
7.5	890	200
10	1,100	235
15	1,480	295
20	1,820	350
25	2,140	400
50	3,540	600
75	4,750	760
100	5,850	900
	1800 REV. PER MIN.	
1	210	$65
2	285	90
3	360	105
4	435	120
5	500	135
7.5	635	160
10	820	190
15	1,100	235
20	1,350	275
25	1,580	315
50	2,640	470
75	3,500	600
100	4,400	710

TABLE XLIV. COST OF ALTERNATING CURRENT GENERATORS

Size, kw.	Weight, lb.	Price f.o.b. factory
	150 REV. PER MIN.	
500	54,500	$8,500
750	72,000	10,400
1,000	87,000	14,000
1,500	124,000	18,600
2,000	140,000	23,000
2,500	161,000	26,800
3,000	182,000	30,500
3,500	203,000	34,000
4,000	222,000	37,500
4,500	240,000	41,000
5,000	260,000	44,000
	360 REV. PER MIN.	
500	30,000	$4,600
750	40,000	6,200
1,000	48,000	7,500
1,500	63,000	10,000

Size, kw.	Weight, lb.	Price f.o.b. factory
2,000	77,000	12,300
2,500	89,000	14,400
3,000	102,000	16,300
4,000	122,000	20,100
5,000	143,000	23,500
6,000	162,000	26,600
7,000	180,000	30,000
8,000	198,000	33,000
9,000	212,000	36,000
10,000	230,000	38,500
12,500	265,000	45,000
500 REV. PER MIN.		
100	13,000	$2,230
250	18,500	2,900
500	25,000	3,800
750	32,000	4,850
1,000	38,500	6,000
1,500	51,000	8,000
2,000	62,000	9,800
2,500	72,000	11,500
3,000	81,000	13,000
4,000	99,000	16,000
5,000	114,000	18,700
6,000	130,000	21,200
7,000	144,000	23,700
8,000	158,000	26,000
9,000	170,000	28,300
10,000	182,500	30,500
800 REV. PER MIN.		
100	10,800	$2,000
150	12,600	2,200
200	14,000	2,360
250	15,300	2,510
300	16,400	2,650
400	18,300	2,900
500	20,500	3,110
750	24,300	3,680
1,000	28,300	4,300
1250 REV. PER MIN.		
100	9,200	$1,800
150	10,400	1,940
200	11,900	2,110
250	13,000	2,220
300	13,900	2,340
400	15,400	2,520
500	16,900	2,700
750	20,000	3,100
1,000	22,500	3,440

TABLE XLV. COST OF CONDENSING STEAM TURBO-GENERATORS

OPERATING AT 750 REV. PER MIN.

Size, kw.	lb. (approx.)	* Price f.o.b. factory
5,000	355,000	$84,000
7,500	450,000	109,000
10,000	530,000	130,000
12,500	600,000	150,000
15,000	675,000	168,000

OPERATING AT 1000 REV. PER MIN.

Size, kw.	Shipping weight lb. (approx.)	* Price f.o.b. factory
17,500	740,000	185,000
20,000	800,000	200,000
1,000	118,000	$25,700
1,500	150,000	33,000
2,000	175,000	40,000
2,500	200,000	46,000
3,000	222,000	51,000
3,500	244,000	56,500
4,000	263,000	61,000
4,500	282,000	66,000
5,000	300,000	70,000
7,500	380,000	91,000
10,000	450,000	109,000
12,500	510,000	125,000
15,000	570,000	140,000

OPERATING AT 1500 REV. PER MIN.

Size, kw.	Shipping weight lb. (approx.)	* Price f.o.b. factory
250	49,000	$11,400
500	64,000	14,000
750	79,000	17,100
1,000	92,000	20,100
1,500	118,000	25,700
2,000	139,000	30,800
2,500	158,000	35,000
3,000	175,000	40,000
3,500	194,000	43,500
4,000	208,000	47,500
4,500	222,000	51,000
5,000	236,000	55,000
7,500	300,000	70,000
10,000	355,000	84,000
12,500	405,000	97,000
15,000	450,000	109,000

OPERATING AT 2400 REV. PER MIN.

Size, kw.	Shipping weight lb. (approx.)	* Price f.o.b. factory
1,000	72,000	$15,500
1,500	89,000	19,500
2,000	105,000	23,000
2,500	120,000	26,400
3,000	134,000	29,500
3,500	145,000	32,500
4,000	157,000	35,000
4,500	168,000	38,000
5,000	179,000	40,800

OPERATING AT 3600 REV. PER MIN.

Size, kw.	Shipping weight lb. (approx.)	* Price f.o.b. factory
250	36,000	$8,900
500	48,000	10,800
750	52,500	12,000
1,000	59,000	13,000
1,500	72,000	15,500
2,000	84,000	18,200
2,500	95,000	20,600
3,000	105,000	23,000

* Price does not include condenser.

Cost of Generators. The following unit costs are from Bulletin 5, Office of the State Engineer, Salem, Oregon, and are based upon estimates of several manufacturers of electrical machinery.

COST OF 3-PHASE, 2300 VOLT, 60-CYCLE, HYDRAULICALLY-DRIVEN GENERATORS

Head, ft.	Cost per kw. output
Under 40	$8.00
40 to 80	7.00
80 to 120	6.00
120	5.00

Exciter turbines and exciters will cost about $0.80 per kw. output of whole plant.

Switchboard and accessories, cables, etc., per kw. output of the whole plant will cost about $2.25.

Transformers, oil insulated and water cooled, 2,300 to 60,000 volts will cost about $4 per kw. output, whole plant.

Turbo-Generators. The following was abstracted from The Isolated Plant, October, 1909.

APPROXIMATE COSTS OF TURBINE SETS, INCLUDING DYNAMOS

kw.	Speed	Price, f.o.b. shop
	NON-CONDENSING	
50	2500–3000	$1900 to $2000
75	1650–2500	2600 — 2800
100	1650–2500	3300 — 3400
150	1650–2000	4500 — 4700
300	1250–1800	9000
	CONDENSING	
75		$3000
300		9500

Generators, Electric. A. A. Potter (Power, December 30, 1913) gives the following formulæ of costs in dollars.

Direct current (voltage 110–250), belted, up to 7 kw. (1400 to 2300 rev. per min.) $21.1 + 28.5 \times$ (kw.)

Direct current (voltage 110–250), belted, 10 kw. to 300 kw. (600 to 1400 rev. per min.) $10 \times$ (kw.) — 9.

Direct-connected up to 300 kw. (100 to 350 rev. per min.), $313.3 + 10.93 \times$ (kw.)

Direct-connected 300 to 1000 kw. (moderate speed $12.08 \times$ (kw.) — 383.

Alternating-current, belted, up to 300 k.v.a. (600 to 1800 rev. per min.) $81 + 9.723 \times$ (k.v.a.)

Direct-connected, up to 300 k.v.a. (200 to 300 rev. per min.) $375 + 7.477 \times$ (k.v.a.)

Direct-connected, 250 to 2500 k.v.a. (100 to 250 rev. per min.) $2413 + 469 \times$ (k.v.a)

Instruments. The following prices of instruments are net, f.o.b. factory, prior to the war.

AMMETERS

Round Pattern Switchboard Type Ammeter, for direct current, especially designed for switchboards on which an illuminated dial type is not desired. These instruments weigh about 15 lbs. apiece, with shipping weight of 22 lbs. and may be obtained in sizes ranging from 0 to 1 amperes to 0–2500 amperes, with scale values of

0.01 for the smallest size to 20 for the largest. The cost of these instruments varies from $25.00 for the smallest instrument to $45.00 for the 2500 ampere size, there being an increase of from $.50 to $3.00 for each 100 ampere increase in range of instrument.

Note. Ammeters are also made in considerably cheaper types to meet a demand for thoroughly serviceable and durable switchboard instruments, but where accuracy is not essential, and a low price is of great importance. Such instruments cost from $12.00 to $18.00 for sizes ranging from 1 to 500 amperes.

Extra Large Illuminated Dial Instruments for Direct Current, for indicating the total output of large central stations, and for use on switchboards, controlling unusually large currents.

Model A — Length of scale, 28 in.; length of pointer, 12 in.
Model B — Length of scale, 38 in.; length of pointer, 18 in.

These models are often found very desirable in connection with electro-chemical work, as their indications can be read with ease and accuracy at a considerable distance.

Range in amperes	Price, Model A	Price, Model B
1,000	$135	$165
1,500	140	170
2,000	143	174
2,500	145	176
3,000	146	178
3,500	150	181
4,000	155	190
4,500	160	192
5,000	167	200
6,000	175	205
7,000	180	212
8,000	195	225
10,000	207	238

Illuminated Dial Station Ammeters, with shunts for direct current.

Range in amperes	Value of scale division in amperes	Price of instrument with shunt	Price of shunt alone
200– 300	2	$72	$3
400– 750	5	73– 75	3– 6
1000– 1,500	10	76– 82	7–13
2000– 3,500	20	85– 92	17–23
4000	30	96	27
4500	40	103	33
5000– 7,000	50	110–123	40–54
8000–10,000	100	136–150	68–81

VOLTMETERS

Round Pattern Switchboard Type D. C. Voltmeters, designed for switchboards on which an illuminated dial type is not desired, in capacities ranging from 0–3 to 0–750 volts with value of each scale division varying from 0.02 to 5 volts, cost from $25.00 for the smaller sizes to $35.00 for the larger sizes, with a variation in price of about $1.00 to $2.00 for each 100 volt increase in size of voltmeter.

The weight of these instruments is 15 lbs. with a shipping weight of 22 lbs.

Note. Voltmeters are also made in considerably cheaper types to meet a demand for serviceable and durable switchboard instruments, but where extreme accuracy is not essential, and a low price is of great importance. Such instruments cost from $12.00 to $18.00 for sizes ranging from 75 to 750 volts.

Extra Large Illuminated Dial Voltmeters for Direct Current. For description see similar type under ammeters.

Range in volts	Price, Model A	Price, Model B
125	$120	$158
150	125	158
250	130	162
300	130	162
600	135	167
750	140	171

Illuminated Dial Station Voltmeters, for direct current.

Volts	Value of each scale division in volts	Price
125– 150	1	$68
180– 300	2	69– 71
600– 750	5	72– 73
1000– 1,500	10	90–100
2000– 2,500	20	108–117
3000– 3,500	25	121–135
4000– 5,000	50	144–162
6000– 6,500	50	175–185
7000– 7,500	50	190–198
8000–10,000	100	210–250

Recording Milli-voltmeters and Voltmeters for d.c. circuits are regularly made in two styles; one using a frictionless ink recording device and the other a patented smoked chart upon which a record is made by a needle coming in contact with the surface.

By the use of these instruments a continuous record is obtained, but due to the delicacy of the instruments and the extremely small potentials at which the millivoltmeters operate it is necessary to eliminate all friction between the tip of the pointer or recording arm and the surface of the chart to obtain an accurate record. In these instruments this is accomplished by bringing the recording arm into contact with the moving surface of the chart only periodically, and between contacts it is left free to take its new position without friction. Standard instruments, except those in which the revolution of the chart is made in one hour's time, are equipped with 10-second vibrators; special vibrators may be obtained, however, recording every half second if required.

The price of these instruments varies from $99 to $108 for instruments using the smoked chart; $99 being the price for standard instruments making 12 and 24 hr. records; $108 is the price for standard instruments making 1 hr. record. These instruments may regularly be obtained for recording from –4–0–4 millivolts in 24 hours up to capacities of 495–770 volts, and from –5–0–5 millivolts in 1 hour up to 375–675 volts.

Instruments using the frictionless recording device cost about $9 more each than those using the smoked charts.

SYNCHROSCOPES

Synchroscopes for determining whether a.c. generators are running with the same frequency and are in phase, made for 100 to 125 volts and any commercial frequency up to 150 cycles, cost about $60 each.

WATTMETERS

Polyphase Wattmeters, with characteristics similar to the single phase type for 100 to 150 volts and from 5 to 50 amperes with a scale reading from 1 kw. to 15 kws. cost $65; for 100 amperes, from 20 kws. to 30 kws. the cost is $70.

For 200 to 300 volts and from 5 to 50 amperes, with a scale reading from 2 kws. to 30 kws., the price is $75 each; for 100 amperes, with a scale reading from 80 kws. to 120 kws. the price is $75 each.

For 400 to 600 volts and from 5 to 50 amperes, with a scale reading from 4 kws. to 60 kws., the price is $75 each; for 100 amperes, with a scale reading from 80 kws. to 120 kws. the price is $80 each.

For 600 to 750 volts and from 5 to 50 amperes, with a scale reading from 5 kws. to 75 kws., the price is $80 each; and for 100 amperes, with a scale reading from 100 kws. to 150 kws. the price is $85 each.

Wattmeters for Single Phase A.C. or D.C. Circuits are back connected and designed for mounting upon switchboards. Meters for a voltage over 300 have external resistance boxes; for ranges above 750 volts potential transformers are used; for current ranges above 100 amperes, current transformers must be used. For use with current transformers the 5-ampere range instrument is recommended.

This type of wattmeter for voltages of from 100 to 150, and for an amperage of from 1 to 50, with the scale recording from 150 watts to 7.5 kws. cost $45 each; for 100 to 150 volts at 100 amperes, with scale reading from 10 to 15 kws.— $50 each.

For 200 to 300 volts and from 1 to 50 amperes, with a scale reading from 300 watts to 15 kws. the cost is $50 each. For 200 to 300 volts at 100 amperes, with a scale reading from 20 to 30 kws. the cost is $55 each.

For 400 to 600 volts and from 1 to 50 amperes, with a scale reading from 600 watts to 30 kws. these wattmeters cost $55 each.

For 400 to 600 volts and 100 amperes, with a scale reading from 40 to 60 kws., the cost is $60 each.

For 600 to 750 volts and from 1 to 50 amperes, with a scale reading from 750 watts to 40 kws., the price is $60 each.

For 600 to 750 volts and 100 amperes, with a scale reading from 50 to 75 kws., the price is $70 each.

Recording Wattmeters may be obtained for either d.c. or a.c. circuits: 12, 8 and 6-in. charts for a.c., and 12 and 8-in. charts for d.c.

These are designed to record electrical energy consumed during periods of from 1 hour to 7 days, and in quantities from a fraction of a kilowatt to many thousand kilowatts.

D.C. Recording Wattmeters, 12-Inch Charts are made in sizes to record from 0 to 90 kws. in 24 hrs. up to 0 to 2500 kws. in 12 hrs.

Capacity		
Volts	Amperes	Price
600 to 750	120 to 150	$87
500 to 750	180 to 300	96
240 to 750	400 to 600	105
120 to 750	800 to 1200	114
250 to 500	2,000 to 2400	123
250 to 750	2,000 to 4000	132
500	5,000	240
250	10,000	330

Prices of D.C. recording wattmeters, 8-inch charts, follow:

Capacity			
Volts	Amperes	Range of chart	Price
5–750	8– 80	0–2.5 to 0– 50	$69
5–500	75– 150	0– 15 to 0– 90	78
125–750	200– 400	0– 25 to 0– 300	87
125–750	600	0– 75 to 0– 450	95
125–750	800–1200	0–100 to 0– 900	105
125–750	2000–2500	0–200 to 0–1500	114
110–250	3,000–4,000	0– 350 to 0–1000	$123
250–500	5,000	0–1250 to 0–2500	230
125–250	10,000	0–1250 to 2500	320

Recording Wattmeters with 8-in. charts for 3-wire, d c. system. The following instruments have chart ranges of from 0–200 to 0–300 kws.

Capacity		
Volts	Amperes	Price
650–750	120– 150	$155
250–500	200– 400	173
250	600	190
125	800–1200	210

Recording Wattmeters for Alternating Current are normally wound for 125 volts and 5 amperes. However, by using a proper combination of series and potential transformers, these meters can be used on currents of practically every amperage and voltage and will record from 0–0.5 to 0–30,000 kws.

For a.c. single phase and 2-phase, meters for 12-in. charts cost $88; for 8-in. charts $79; for 6-in. charts $61.

Balanced 3-phase meters for 12-in. charts cost $102; for 8-in. charts $92, and for 6-in. charts $74.

With unbalanced 3-phase circuits a special instrument has been developed which sells for $126.

WATTHOUR METERS

Watthour Meters for Alternating Current, 2- and 3-phase, 25, 40 and 60 cycle.

Size in amperes	Net price 100 to 100 volts	Net price 200 to 220 volts	Net price 400 to 440 volts
3	$19.00	$21.00	$30 00
5	21.00	23.00	31.50
10	24.00	26.00	34.50
15	26.00	28.00	36.00
20	27.00	29.25	37.00
25	28.00	30.50	38.00
30	29.00	31.50	39.00
40	31.00	33.00	40.50
50	32.00	35.00	41.50
75	34.00	37.00	44.00
100	36.00	39.00	45.00
150	39.00	42.00	48.00
200	41.00	45.00	50.00

Watthour Meters for Alternating Current, Single Phase 40 to 133 Cycle.

Size, amperes	Net price 100 to 110 volts	Net price 200 to 220 volts	Net price 400 to 440 volts
5	$6.50	$7.25	$7.75
10	7.50	8.25	8.75
15	8.75	9.50	10.00
20	10.00	10.50	11.50
25	11.00	11.50	12.75
30	11.75	12.50	13.50
40	13.00	14.00	15.00
50	14.50	15.00	16.50
75	16.50	17.50	19.00
100	18.00	19.00	21.00
150	20.00	21.50	23.00
200	21.00	22.50	24.00
300	21.00	23.00	25 00

PANELS

Panels for large size installations are usually made to order. The following costs of standard switchboard material may be found useful in estimating the cost of special panels.

Angle Iron Frames made of 2 by 1.5 by .1875 in angle iron, given one coat of black paint and provided with angle iron support or cross connecting piece so that switchboard does not have to depend on bolts for support, cost about as follows.

Size of panels	Length of legs, in.	Price
18 by 48	24	$3.50
18 by 54	24	3.80
18 by 60	18	3.80
18 by 66	18	3.95
18 by 72	12	3.95
24 by 48	24	3.70
24 by 54	24	3.90
24 by 60	18	3.90
24 by 66	18	4.05
24 by 72	12	4.10
36 by 48	24	3.90
36 by 54	24	4.05
36 by 60	18	4 10
36 by 66	18	4.10
36 by 72	12	4 10
42 by 48	24	4 00

Size of panels	Length of legs, in.	Price
42 by 54	24	4.15
42 by 60	18	4.00
42 by 66	18	4.15
42 by 72	12	4.15

Channel Iron Base for these frames, 4 in., price per ft. $0.50
" " " " " " 6 in., price per ft. 1.10

Wall Braces for supporting and stiffening panels. These are of two types. One made of .5 in. pipe with flange; and the other is made of .5 in. pipe with adjustable turn buckle.

Prices are as follows:

	Iron pipe braces (with flange)	Adjustable braces (with turn buckles)
12 in.	$ .40	...
18 in.	.60	$1.60
24 in.	.75	1.80
36 in.	1.10	2.00
48 in.	1.45	2 25
60 in.	...	2.95

Switchboard Bolts for holding marble or slate to frame. These bolts are complete with washers, bolts and polished copper capnut.

Thickness of panel, in.	Size, in.	Price
1¼	½ by 2	$0.30
1½	½ by 2¼	0.35
2	½ by 2¾	0.35

Pilot Brackets including base sockets, 2.25 in. shade holders, wired and ready for mounting on switchboard. (Price does not include the shade.)

One light	$1 25
Two light	2.20
½ pear porcelain green shade	0.50
½ pear tin shade	0.25

Slate for Electrical Use. Black slate, oil finish.

Thickness, in.	1 to 3 sq. ft.	3 to 8 sq. ft.	8 to 12 sq. ft.	12 to 15 sq. ft.	15 to 20 sq. ft.	20 to 25 sq. ft.
1 or less	$.60	$.64	$.77	$.80	$.88	$.93
1 to 1¼ incl.	.62	.67	.79	85	.92	.98
1¼ to 1½ incl.	.68	.71	.85	.89	.97	1.04
1½ to 2 incl.	.79	.84	.99	1.01	1.06	1.10

The cost of beveling the edges is: ¼ in beveled, 1 ct. per lin. ft.; ⅜ in. beveled, 2 ct. per lin. ft.; ½ in. beveled, 3 ct. per lin. ft.

Marble for Electrical Use.

Thickness, in.	Prices per sq. ft. Pink or gray Tennessee	Blue Vermont	White Italian
⅞ or less	$1 13	$1.35	$1.45
1 or less	1.24	1.45	1.55
1¼ or less	1.45	1.75	1.85
1½ or less	1.75	2.05	2.28
2 or less	2.38	2.48	3.00

Prices for drilling holes and counter-sinking.

Diam., in.	Per hole
¼	$0.10
½	0.14
¾ to 1	0.20
1¼ to 1½	0.25
2	0.30

Slate Panels.

Size in. width	Thickness	Bevel	Net price per sq. ft. Black marine	Black enamel	Black oil finish
16	1	¼	$0.95–1.00	$1.70–1.80	$1.20–1.35
12–32	1¼	⅜	1.00–1.10	1.80–1.90	1.55–1.80
12–32	1½	⅜	1.10–1.15	1.85–2.05	1.80–2.05
16–48	2	½	1.25–1.75	2.00–2.60	2.15–3.20

Marble Panels

Size in. width	Thickness	Bevel	Black marine	Veined marble	White Italian
16	1	¼	$1.30–1.50	$1.80–2.10	$2.45–2.85
12–32	1¼	⅜	1.35–1.45	1.85–2.20	2.60–3.00
12–32	1½	⅜	1.65–1.70	2.15–2.40	3.20–3.55
16–48	2	½	1.80–2.15	2.40–2.75	4.30–4.95

Both slate and marble panels are made in sizes varying from 1 to 5 ft. in length; in general the larger slabs costing more per sq. ft. The weight of marble panels is 13.7 lbs. per sq. ft. per inch of thickness and the weight of slate panels is 14.6 lbs. per sq. ft. per inch of thickness.

Alternating-Current Switchboard Costs. Mr. J. Wilmore in the Electrical World, August 21, 1915, gives the following data.

TYPES OF ALTERNATING-CURRENT SWITCHBOARD PANELS

Switchboard Panels with the numbers designating Instruments and other equipment.

1 — Alter. current ammeter.
2 — Indicating wattmeter.
3 — Field ammeter.
4 — Alter. current voltmeter.
5 — Power-factor meter.
6 — Synchronizing Lamp.
7 — Voltmeter receptacle.
8 — Synchronizing receptacle.
9 — Rheostat.
10 — Field discharge switch.
11 — Ground detector lamp.
12 — Ground detector receptacle.
13 — Ground detector push.
14 — Single-phase relay.
15 — Recording watt-hour meter
16 — Non-automatic oil switch.
17 — Auto. oil circuit breaker.
18 — Card holder.
19 — Ammeter receptacle.
20 — Graphic record. wattmeter.
21 — Direct-current ammeter.
22 — Knife Switch.
23 — Direct-current voltmeter.
24 — Carbon breaker (shunt trip and reverse current relay.)

The self-contained switchboard, as distinguished from the remote-control and electric operated types, has been found in practice to be the most desirable for three-phase alternating-current plants of a rating up to and not exceeding 3000 kva. and a poten-

tial of 2500 volts or less. Modern power-station practice has practically standardized the switchboard equipment, and the large manufacturers now carry a line of various panels which are known as "standard units." By choosing from these stock units, a complete switchboard for any installation may be easily made up.

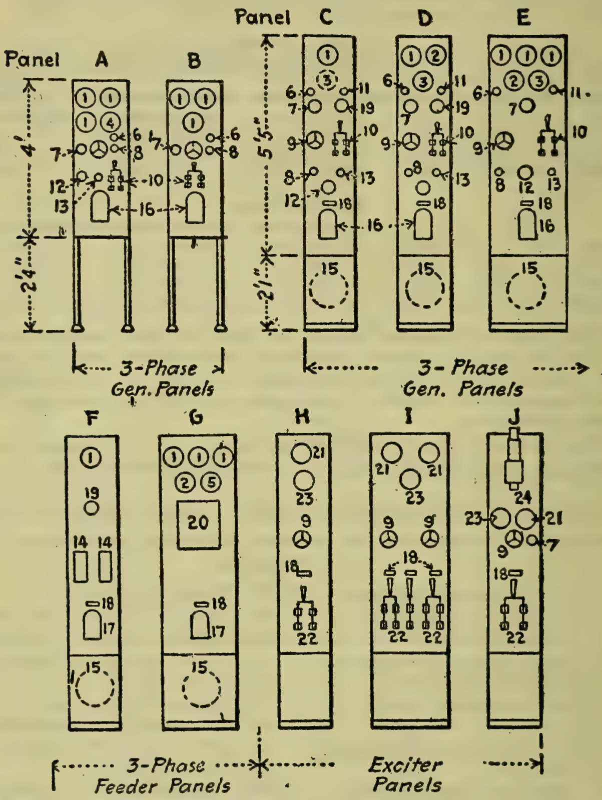


Fig. 15. Types of alternating-current switchboard panels.

These panels are usually made of black marine or natural black slate, mounted on angle iron or pipe frames, being 90 in. high with two or three sections of slate covering the entire frame from top to floor, or 76 ins. high for the smaller and lighter panels, with one section of slate 48 ins. high and the exposed frame extending to the floor.

The 90-in. panels in 2 sections are made up of either a 65-in. top section and 25-in. lower section or 62-in. and 28-in. sections respectively. A 90-in. panel in 3 sections has a 20-in. upper section, 45-in. middle and 25-in. lower section, or 28-in., 31-in. and 31-in. sections respectively. These sections are 24 ins., 20 ins. or 16 ins. wide. The thickness of slate is usually 1.5 ins.

The cost data in Table XLVI, which may be used for estimating or for purposes of power comparison, are based on figures recently published in a series of papers by C. H. Sanderson and H. A. Travers. The values given are for three-phase, 2200-volt panels completely wired, corresponding to the ratings listed in the tabulations covering the various switchboard panels shown in the illustrations. These panels represent a form of standard units and are typical of self-contained switchboards.

TABLE XLVI. RATINGS AND COST OF SWITCHBOARD PANELS

Panel	Type (Fig. 15)	Rating, kva.	Approximate cost per panel
Generator	A	100– 200	$34
		250– 800	44
		1000–1200	52
Generator	B	10– 200	63
Generator	C	25– 500	122
		600–1200	139
		1400–2250	213
Generator	D	25– 500	175
		600– 800	180
		1000–1200	192
		1400–2250	265
Generator	E	25– 500	210
		600– 800	215
		1000–1200	228
		1400–2250	300
Feeder	F	25–1200	170
		1400–2250	215
Feeder	G	25–1200	400
		1400–2000	445
Exciter	H	4– 25	75
		35– 45	81
		55– 75	90
		150– 200	129
Exciter	I	4– 25	116
		35– 45	125
		55– 75	139
		150– 200	195
Exciter	J	4– 25	110
		35– 45	121
		55– 75	135
		150– 200	210

FEEDER REGULATORS

Automatic, 2300 V. 10% B. of B.

Amperes	Kva.	Shipping weight, lbs.	Net price f.o.b. factory	Cost of installing	Total cost
50	11.50	1,600	$519	$20	$539
75	17.25	1,800	585	20	605
100	23.00	2,025	632	22	654
150	34.50	3,050	756	31	787

Amperes	Kva.	Shipping weight, lbs.	Net price f.o.b. factory	Cost of installing	Total cost
200	46.00	3,600	940	36	976.
250	57.50	4,250	1,068	43	1,111
300	69.00	5,000	1,282	50	1,332
500	345.00*	....	3,400	200	3,600
...	500.00	18,000	4,850	250	5,100
25	5.75	785	$216	$10	$226
50	11.50	897	247	10	257
75	17.25	910	270	10	280
100	23.00	1,150	296	12	308
150	34.25	1,510	384	16	400
200	46.00	1,760	476	18	494
Automatic, oil cooled, single phase 2200 v. 10% B. of B.					
100	22.0	2,500	$538	$25	$563
200	44.0	3,500	800	35	835
Automatic, water cooled, two phase, 2300 v. 15% B. of B.					
...	500	16,640	$6,400	$160	$6,560
Motor operated, 2300 v. 10% B. of B.					
...	1	300	$144	$10	$154
...	3	520	185	10	195
...	6	900	302	12	314

*15% B. of B. hand operated 2300 V., 10% B. of B.

SHUNTS

Standard Switch Board Shunts, for all types of switchboard ammeters.

Capacity, amperes, for d.c.	Weight, lb.	Price
25– 200	0.75– 1	$3
300– 500	1.25	3– 4
600– 800	1.5– 2	5– 7
1,000–1,200	6.0– 6.75	7– 8
1,500	8.5	13
2,000	12.5	17
2,500	20.0	19
3,000–3,500	28.0–30	20–23
4,000	36.0	27
4,500	44.0	34
5,000	45.0	41
6,000	55.0	48
7,000	65.0	44
8,000	70.0	68
9,000	80.0	75
10,000	95.0	81
12,000	105.0	108
15,000	140.0	150
18,000	155.0	190
20,000	175.0	220

SWITCHES

Motor Starting Switches, plain finished; front connection; mounted on oil slate bases.

Switches of this type are used with alternating current motors, having excessive starting current and therefore requiring fuses on switch to be temporarily cut out of circuit. The knife blades in

starting are held against a spring pressure bar which is powerful enough to prevent the switch being left in the starting position. After the motor has come up to speed the blades are reversed and thrown to the fused end of the switch, in which position the fuses are in circuit to protect the motor.

DOUBLE POLE

High Grade

Capacity, amperes	Price, each	Shipping weight, lb.
30	$2.00	6
60	2.75	11
100	5.25	21
Punched Clip		
30	1.85	5
60	2.40	11
100	5.00	19
THREE POLE		
30	2.75	8
60	3.65	16
100	7.00	23
Punched Clip		
30	2.50	7
60	3.30	15
100	6.60	21
FOUR POLE		
30	3.65	10
60	4.90	20
100	9.90	28
Punched Clip		
30	3.35	9
60	4.20	18
100	8.80	26

Note. The above prices and weights are for switches for not over 250 volts. Switches for 500 volts, high grade type cost about 30% more for the 30 ampere size, 20% more for the 60 ampere and about 10% more for the 100 ampere size; and weigh about 2 lbs. per switch more than for 250 volts.

Switches of the punched clip type for 500 volts cost about 20% more in the 30 and 60 ampere sizes; and about 10% more in the 100 ampere sizes. These switches also weigh about 2 lbs. more per switch than those listed.

Disconnecting switches and thin installation front connected, single pole, single throw:

Type	Volts	Amperes	Net price, f.o.b. factory
M.B.	2,500	300	$4.95
M.B.	2,500	600	7.65
M.B.	2,500	800	10.35
M.B.	2,500	1,200	13.50

TABLE XLVII. HAND OPERATED OIL SWITCHES FOR PANEL MOUNTING, SWITCH ON PANEL *

Capacity		Double pole				Triple pole				Four pole			
		Single throw		Double throw		Single throw		Double throw		Single throw		Double throw	
Amperes	Voltage	Approx. sh. wt.	Price	Approx. sh. wt.	Price	Approx. sh. wt.	Price	Approx. sh. wt.	Price	Approx. sh. wt.	Price	Approx. sh. wt.	Price
Without overload release — non-automatic.													
300	600	160	$27	260	$51	170	$33	280	$60	230	$39	350	$72
500	600	170	34	290	61	190	42	310	75	250	54	410	92
800	600	190	55	...	...	200	73	...	...	260	96	...	...
200	4,500	150	27	250	51	160	32	270	59	180	39	320	71
300	7,500	180	34	290	61	190	41	310	75	250	51	400	92
500	7,500	190	40	300	69	200	51	320	87	260	64	420	109
With automatic overload release. With one trip coil and current transformers.†													
300	600	220	$51	330	$77	250	$71	380	$100	300	$77	440	$113
500	600	240	59	360	88	270	83	410	118	320	95	490	135
800	600	250	81	...	...	280	116	...	...	330	138	...	...
200	4,500	200	51	320	76	230	69	360	98	260	76	410	110
300	7,500	240	58	360	87	270	80	410	115	320	89	490	133
500	7,500	250	66	370	97	280	92	420	130	330	105	500	152
With automatic overload release. With two trip coils and current transformers.†													
300	600	...	...	...	...	260	$78	390	$106	310	$85	450	$119
500	600	...	...	...	...	280	90	420	124	330	102	500	141
800	600	...	...	...	...	290	123	...	...	340	141	...	...
200	4,500	...	...	...	...	240	72	370	104	270	84	420	116
300	7,500	...	...	...	...	280	87	420	121	330	97	500	139
500	7,500	...	...	...	...	290	99	430	136	340	112	510	158
With automatic release. With three trip coils and three current transformers (ΔΔ)													
200	45.00	...	...	...	...	290	$102	420	$127	320	$109	470	$139
300	75.00	...	...	...	...	330	113	470	145	380	122	550	162
500	75.00	...	...	...	...	340	126	480	161	390	139	560	183

* For footnotes see page 873.

Type	Volts	Amperes	Net price, f.o.b. factory
M.B.	2,500	1,500	25.20
M.B.	2,500	2,000	39.60
M.B.	2,500	3,000	54.90
M.B.	2,500	300	6.75
M.B.	7,500	300	9.00
M.B.	7,500	600	11.25
M.B.	7,500	800	15.75
M.B.	7,500	1,200	23.80
M.B.	7,500	2,000	67.50
S.B.	7,500	300	7.20
S.B.	7,500	600	9.45
S.B.	7,500	800	13.95
S.B.	7,500	1,200	21.10
S.B.	7,500	2,000	62.10
M.B.	15,000	300	11.25
M.B.	15,000	600	14.40
S.B.	15,000	300	9.00
S.B.	15,000	600	11.70
M.B.	22,000	300	16.20
S.B.	22,000	300	13.50
S.B.	35,000	300	18.00
S.B.	45,000	300	26.10
S.B.	70,000	100	34.20
S.B.	70,000	300	67.50
Safety catches — all sizes			5.40

M.B.— Marble base.
S.B.— Steel base.

The estimated cost installing these switches is as follows:

Volts	Cost of installing	Volts	Cost of installing
2500–15000	$1	45000	4
22000	2	70000	5
35000	3		

* Oil switches for panel mounting with switch on panel pipe 5-in. back of panel cost about $2 to $3 more and weigh about 10 lb. more for the non-automatic type and about 80 lb. more for the automatic type.

† Double pole switches have 1 transformer. Triple and four-pole switches have 2 transformers, these are also furnished with 3 transformers △ at a cost of about $15 more and weigh about 30 lb. more than those listed.

Switches for the higher voltages are also made for "remote control," with switch on framework, at a cost of from about $10 to $15 more for the single throw and from about $25 to $30 more for the double throw switches.

Distributing Transformers. The prices and weights given are for transformers for single phase 60 cycle currents. Three phase transformers for same voltages and cycles cost from about 15 to 25% more than those listed and 25 cycle about 30–40% more.

There is considerable variation in the weights and prices of the same transformers among different manufacturers, also in the prices quoted by any one of the manufacturers depending upon the quantity ordered. In general we have found variations of 20% both more and less than the prices and weights given.

TABLE XLVIII. OIL SWITCHES, AUTOMATIC, ELECTRIC OPERATED

Capacity Am-peres	Capacity Volt-age	Double pole Single throw Cost Switch only	Double pole Single throw Cost Complete installed	Triple pole Single throw Cost Switch only	Triple pole Single throw Cost Complete installed	Four pole Single throw Cost Switch only	Four pole Single throw Cost Complete installed
			1 — Cell mounted.				
300	2,500	....	....	....	....	$210	$271
300	7,500	....	....	....	....	250	315
200	12,000	....	....	....	....	210	271
						240	300
300	15,000	$190	$245	....	....	250	315
						250	311
500	....	....	....	....	....	250	310
						260	326
800	....	....	....	....	....	260	325
			2 — Cell mounted				
300	15,000	$204	$270	....	....	....	....
500	15,000	211	277	....	....	....	....
			3 — Cell mounted				
300	2,500	....	....	$694	$774	....	....
500	2,500	....	....	714	794	....	....
800	2,500	....	....	866	951	....	....
1,200	2,500	....	....	932	1,027	....	....
2,000	2,500	....	....	1,428	1,536	....	....
				1,853	1,973		
3,000	2,500	....	....	1,800	1,920	....	....
2,000	3,300	....	....	860	970	....	....
300	4,500	....	....	273	349	....	....
500	4,500	....	....	281	357	....	....
300	7,500	....	....	278	354	....	....
500	7,500	....	....	280	356	....	....
800	7,500	....	....	340	421	....	....
1,200	7,500	....	....	370	456	....	....
2,500	12,000	....	....	1,500	1,610	....	....

3 — Cell mounted

Triple pole — Single throw

Capacity Amperes	Capacity Voltage	Switch only	Complete installed
100	15,000	$278	$354
300	15,000	278	359
300	15,000 (H3.)	694	777
500	15,000 (H3.)	714	797
600	15,000	706	787
800	15,000 (H3.)	866	954
		845	931
1,200	15,000 (H3.)	932	1,030
		1,532	1,636
2,000	15,000 (H3.)	1,428	1,538
600	25,000	1,030	1,129
1,200	25,000	1,166	1,270
300	35,000	1,000	1,091
400	60,000	1,100	1,230

4 — Cell mounted

Four pole — Single Throw

300	2,500	$948	$1,049
500	2,500	973	1,074
800	2,500	1,178	1,284

Capacity — Amperes	Capacity — Voltage	Switch only	Complete installed
1,200	2,500	1,260	1,371
2,000	2,500	1,936	2,061
300	15,000 (H3.)	948	1,053
500	15,000 (H3.)	973	1,078
800	15,000 (H3.)	1,178	1,288
	(K.12)	332	423
300	15,000 (K.4)	332	428

FLOOR MOUNTED

Triple pole — Single throw

300	22,000	614	644
300	45,000	678	718
150	.....	1,703	1,778
300	55,000	1,166	1,226
150	70,000	1,166	1,226
150	70,000	1,703	1,778
150	70,000	1,001	1,051

DISTRIBUTING TRANSFORMERS

Single phase, 60 cycle; high tension side — 1100, 1200, 2200 and 2400 volts. Low tension side — 110,120,220 and 240 volts.

Size, kw.	Shipping weight, lb. (approx.)	Net price
1	145	$22
1.5	160	27
2	175	32
2.5	210	36
3	235	40
4	285	47
5	340	55
7.5	475	74
10	600	91
15	820	123
20	1,020	152
25	1,220	180
30	1,400	205
40	1,770	255
50	2,050	300
75	2,600	390
100	2,950	465
150	3,400	575
200	3,650	650

Single phase, 60 cycle; high tension side — 6,600 volts; low tension side — 110–220–440 volts.

Size, kw.	Shipping weight, lb. (approx.)	Net price
1	280	$47
1.5	290	50
2	300	54
2.5	310	58
3	330	62
4	375	70
5	425	78
7.5	550	100
10	650	122
15	830	160
20	1,020	195
25	1,220	225
30	1,400	254

Size, kw.	Shipping weight, lb. (approx.)	Net price
40	1,800	310
50	2,100	360
75	2,800	470
100	3,400	550
150	4,250	660
200	4,800	730

Capacity, 200 volt-amperes. Secondary voltage, 100.

Primary voltage at 100 v. secondary	25 cycles Shipping, weight, lb.	25 cycles Net price	60 cycles Shipping, weight, lb.	60 cycles Net price
		Dry type		
200	53	$17	42	$15
400	55	18	42	15
500	55	18	45	16
600	62	19	53	16
1,000	62	20	53	18
2,000	64	24	53	20
3,000	85	27	58	23
4,000	93	30	75	25
5,000	100	32	80	28
6,000	115	37	85	31
		Oil insulated type.		
200	77	$24	77	$21
400	80	25	77	22
500	80	26	77	23
600	80	26	77	24
1,000	88	28	77	25
2,000	110	29	77	26
3,000	115	31	85	28
4,000	130	51	120	41
5,000	145	53	125	43
6,000	150	56	130	45
10,000	210	75	190	64
12,000	250	88	215	73
15,000	320	143	270	126
20,000	350	167	285	156
25,000	385	226	350	184
30,000	410	240	380	204
40,000	900	478	815	378
50,000	925	536	835	402
60,000	925	616	835	431

CURRENT TRANSFORMERS

Current Transformers are used for one or both of two purposes, namely, to reduce the currents to be measured to the relatively small values suitable for measuring instruments, relays and circuit breaker trip coils, or to insulate meter circuits from high line voltage. They are used wherever the current exceeds 5 amperes and should be used wherever the line voltage exceeds 1000.

The following table shows the range in weights and costs of several types and makes of Current Transformers. As a general rule these transformers are made in the following sizes — 5, 10, 15, 20, 25, 30, 40, 60, 80, 100, 150, 200, 250, 300, 400, 500, 600, 800, 1,000 amperes primary and a close price and weight may be obtained by interpolating. These transformers may be used on cir-

cuits of all commercial frequencies. The current in the secondary winding is 5 amperes in every case.

Dry Type.

Maximum voltage	Primary amperes	Approx. wt. boxed, lb.	Price
2,500	5–500	32	$10–$13
2,500	5–800	24– 28	13– 19
2,500	5–800	48– 57	21– 31
8,000	5–1,000	44– 50	21– 34
15,000	5–800	82– 83	34– 44
17,000	5–600	51– 54	32– 41
24,000	5–500	142–146	45– 55

Oil Insulated

27,000	5/10–400/800	460	$93
35,000	5–400	......	78–102
45,000	5/10–400/800	540	125
47,000	5–400	......	192–213
70,000	5/10 -200/400	1,060	250
70,000	5–400	......	223–247

STATION AND SUB-STATION TRANSFORMERS

Size in kw.	Weight (approx.) Oil	Weight (approx.) Case, coils and iron	Weight (approx.) Total	Net price, High tension side voltages 6300–20,000	Net price, High tension side voltages 20,000–50,000	Net price, High tension side voltages 50,000–100,000
100	3,500	5,300	8,800	$580	$850	$1,000
150	4,000	6,400	10,400	720	1,040	1,220
200	4,300	7,200	11,500	840	1,200	1,400
250	4,600	8,000	12,600	940	1,350	1,580
300	4,900	8,700	13,600	1,040	1,500	1,730
350	5,200	9,300	14,500	1,130	1,600	1,870
400	5,400	10,000	15,400	1,200	1,700	2,000
500	5,800	11,000	16,800	1,380	1,930	2,230
750	6,800	13,000	19,800	1,700	2,370	2,730
1,000	7,300	15,000	22,300	2,000	2,730	3,150
1,500	8,400	17,800	26,200	....	....	3,850
2,000	9,200	20,300	29,500	....	....	4,500
2,500	9,800	22,400	32,200	....	....	5,000
3,000	10,400	24,300	34,700	....	....	5,500
4,000	11,400	27,800	39,200	....	....	6,300
5,000	12,300	30,700	43,000	....	....	7,000
6,000	13,000	33,500	46,500	....	....	7,700
7,000	13,800	36,000	49,800	....	....	8,400
8,000	14,300	38,000	52,300	....	....	9,000
9,000	15,000	40,000	55,000	....	....	9,500
10,000	15,400	42,000	57,400	....	....	10,000

Transformers. A. A. Potter (Power, Dec. 30, 1913) gives the following formulas of costs of transformers.

Type	Capacity	Equation of cost in dollars
Air-cooled	Sizes up to 3000 kva.	439 + 1.467 x (kva.)
Oil-cooled	Sizes up to 30 kva. 25 cycles	52.9 + 8.1 x (kva.)
Oil-cooled	Sizes up to 30 kva. 60 cycles	26.2 + 6.25 x (kva.)
Oil-cooled	Sizes 30 to 100 kva. 25 cycles	157 + 4.68 x (kva.)
Oil-cooled	Sizes 30 to 100 kva. 60 cycles	119.5 + 3.57 x (kva.)
Water-cooled	Sizes 100 to 1000 kva.	181. + 1.725 x (kva.)
Water-cooled	1000 to 3000 kva.	805 + 1.099 x (kva.)

CHAPTER XI

OVERHEAD ELECTRICAL TRANSMISSION AND DISTRIBUTION

Chapter XX, Electric Railways, contains additional data on overhead construction.

Cost of Wooden Poles. The cost of wood poles varies greatly with market conditions and distance from the shipping point. By far the largest number of poles is produced in the Northwest, and unless freight rates are excessive, poles from this section will usually compete in price with "local" poles.

The prices given in Table I are averages of pole costs from a number of recent appraisals by the authors and indicate the relative prices for different sizes of wood poles.

TABLE I. COST OF WOOD POLES

Length, ft.	Diam., top, ins.	Average price, cedar poles	Average price, chestnut poles
25	5	$1.48	...
	6	2.62	$1.38
	7	3.44	2.00
30	6	3.80	2.12
	7	5.03	3.00
	8	6.23	4.00
35	6	5.57	3.50
	7	7.80	4.38
	8	8.93	4.75
40	7	9.63	5.50
	8	10.61	5.75
45	7	12.10	6.50
	8	13.92	7.00
50	7	14.81	8.50
	8	16.77	8.75

Table IA gives the average price of poles in Seattle, Wash., for the years 1912 to 1915 inclusive, made up from prices quoted from several of the largest dealers.

TABLE IA. AVERAGE PRICE OF CEDAR POLES IN SEATTLE, WASH., FOR PERIOD 1912–1915 INCLUSIVE

Height, ft.	Diam of top, ins.	Average price
25	6	$1.86
30	7	2.23
30	8	2.70
35	8	2.97
35	9	3.43
40	8	3.39
45	9	4.65
40	9	3.92

Height, ft.	Diam of top, ins.	Average price
50	9	5.17
55	9	5.83
60	9	6.68
65	9	7.93
70	9	10.20
75	9	11.93
80	9	16.11
85	9	19.38
90	9	22.66
95	9	23.91
100	9	25.18

Weights of Chestnut and Cedar Poles. Fig. 1 shows the weights of chestnut and cedar poles of various lengths and sections as determined by actual measurement of a large number of poles made in connection with recent appraisal work of the authors.

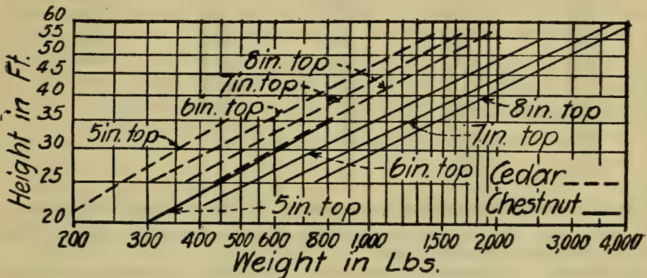


Fig. 1. Weight of wood poles.

Gillette's Handbook of Cost Data, p. 952, has a table of cu. ft. of wood per lin. ft. of poles of different dimensions.

Cedar Poles, Shipping Data. We have taken the data in Table II from "American Telephone Practice," by Kempster B. Miller.

TABLE II. SHIPPING WEIGHT OF CEDAR POLES

Diam. top, ins.	Length, ft.	No. in load	Weight, lbs. Green	Weight, lbs. Seasoned
		IN SINGLE CARS		
4	25	175 to 225	200	155
5	25	150 to 200	260	200
6	25	100 to 125	325	250
7	25	75 to 100	425	350
6	30	75 to 100	425	350
7	30	60 to 80	500	450
7	35	55 to 75	750	650
		IN DOUBLE CARS		
7	40	60 to 75	1,075	850
7	45	50 to 65	1,150	1,000
7	50	40 to 50	1,400	1,250
7	55	35 to 45	1,875	1,650
7	60	25 to 35	2,300	2,000
7	65	20 to 25	2,800	2,500

Weight Saved by Seasoning Wood Poles. The following taken from Circular 136, U. S. Dept. of Agriculture, Forest Service, is for Arborvitæ (White Cedar). Table III shows the weight per cent. saved on poles cut at various times of the year and seasoned for varying periods. Seasoning took place for the most part under very favorable conditions. The ground was rather of a sandy soil which held no moisture and the other conditions were such that the sun's rays and the wind had free access to the poles.

TABLE III. PER CENT. OF FREIGHT WEIGHT SAVED BY SEASONING POLES

Time seasoned, days	Spring cut %	Summer cut %	Autumn cut %	Winter cut %
30	13.2	11.0	...	...
60	15.7	16.5	...	...
90	16.3	18.0	...	1.8
120	16.3	18.0	...	19.6
150	16.3	18.0	0.9	25.1
180	16.3	18.0	20.2	27.5
210	16.3	18.0	25.5	29.2
240	16.3	18.7	28.0	...
270	16.3	22.6	28.9	...
300	16.3	25.4	...	...
330	18.5	26.9	...	...
360	23.2	28.1	...	...
390	24.5	...	...	...
420	25.4	...	...	...

Detail Cost of Preparing and Setting Wooden Poles. The following data were determined by studies of the operations as conducted in the state of Washington.

Unloading. A team and driver at $6 and a laborer at $2.50 per 8 hour day can unload from a car per day 300 25 ft., 200 30 ft., 160 35 ft., 96 50 ft., or 60 70 ft. poles at a total cost of $8.50, averaging 2.8 cts., 4.2 cts., 5.25 cts., 8.75 cts., and 14 cts. per pole respectively.

Shaving. One man at $2.50 per 8 hr. day can shave 6 25 ft., 5 30 ft., 4 35 ft., 3 40 ft., 2 50 ft., or 1 70 ft. pole per day, averaging 40 cts., 48 cts., 60 cts., 80 cts., $1.20 and $2.40 per pole respectively.

Cutting Gains. Two men at $2.40 per 8 hr. day cutting an average of 1 gain can handle and gain 96 35 ft., 65 50 ft., 40 70 ft. poles, averaging 5 cts., 7.39 cts. and 12 cts. respectively. In cutting 2 and 4 gains into 25 and 30 ft. poles respectively it was found that one man could handle and gain 64 25 ft. poles and 32 35 ft. poles, making an average cost per gain in poles of these sizes of 1.9 cts.

Roofing. Two men at $2.40 per 8 hr. day can roof 125 25 ft., 100 30 to 35 ft., 64 40 to 50 ft., and 35 70 ft. poles, averaging 3.84 cts., 4.8 cts., 7.5 cts. and 13.7 cts. per pole respectively.

Hauling. It was found that, hauling against fairly steep grades, the following average loads could be handled for a maximum number of trips as given. Three loads of seven 25 ft. poles, three loads of four 35 ft. poles; 3 loads of two 50 ft. poles. The number of poles carried per load and number of loads would, of course, vary somewhat, depending upon the grades and length of haul.

Digging Holes. One man at $2.50 per 8 hr. day can average in gravel 3 6 ft. holes or 5 4.5 ft. holes per day, giving a unit cost of 83.3 cts. and 50 cts. respectively.

Actual costs for a large number of 35 ft. poles set in hard pan, earth and gravel averaged $1.35 per pole. Holes for 50 ft. poles cost about 24% more or $1.68 and holes for 70 ft. poles cost about 58% more or $2.14.

Erecting and Tamping. One lineman, 8 hrs. @ $.50 ($4.00) and 12 helpers, 8 hours @ $.30 ($28.80) can set and tamp 35 35 ft. poles, 24 50 ft. poles, or 10 70 ft. poles, at a cost of $32.80. 10% should be added for foreman's wages which are $3.28, the total being $36.08, averaging $1.03, $1.50 and $3.61 respectively.

On another job there were five men at $2.50, a lineman at $3.75 and a foreman at $4.25 which constituted an ordinary pole setting gang, making a daily cost of $20.50 per day. This outfit set twenty 30 to 35 ft. poles per day at a cost of about $0.95 and $1.03 respectively. This same gang set 30 25 ft. poles at a cost of 70 cts. per pole.

Painting. One man at $4.00 per 8 hr. day using 8 gals. of paint at $.70 ($5.60) can paint 12 35 ft. poles at a total cost of $9.60 averaging $.80 per pole. Add 110% for 50 ft. poles and 213% for 70 ft. poles. 25 ft. and 30 ft. poles cost about 51 to 57 cts. per pole.

Boring and Placing Steps. One man at $2.40 per day can bore for steps at a cost of 16 to 20 cts. per pole and same man can place them for 12 to 16 cts. per pole.

Table IV gives a summary of the approximate detail cost of different sizes of poles, the cost being taken from several large jobs on the Pacific Coast.

TABLE IV. DETAIL COST OF WOOD POLES *

Length of pole, ft	25	30	35	40	50	70
Cost of pole	$1.70	$2.70	$3.05	$4.00	$5.50	$9.80
Freight	.35	.23	.26	....	.50	3.00
Unloading	.03	.05	.05	.06	.09	.14
Shaving	.42	.48	.60	.80	1.20	2.40
Gaining	.04	.05	.05	.08	.07	.12
Roofing	.04	.05	.06	.08	.08	.14
Hauling to job	.40	.84	.85	.93	1.68	3.36
Digging hole	.50	1.33	1.33	.90	1.65	2.10
Setting and tamping	.70	.95	1.03	1.13	1.50	3.61
Hauling surplus earth	...	...	.02	.04	.02	.02
Total, unpainted and unstepped	$4.18	$6.68	$7.30	$8.02	$12.29	$24.69
Painting	$0.51	$0.57	$0.80	....	$1.88	$2.50
Boring for steps	.16	....	.20	....	....	....
Placing steps	.12	....	.16	....	....	....
Galvanized steps	.24	....	.36	....	....	....
Wood steps	.10	....	.10	....	....	....
Total painted and stepped	$5.31	....	$8.92	....	....	....
Total, painted only	$4.69	$7.25	$8.10	....	$14.17	$27.19

* Add $1.50 for each pole set in pavement.

Cost of Digging Holes and Setting Poles. The following data were taken from a recent appraisal in South California. Table V gives the number of holes dug in dry earth by a gang of 1 foreman and 10 groundmen and the number of poles set per day by the same gang with the addition of 1 lineman. The cost given was determined by the following scale of wages:

1 Foreman at $4.20	$4.20
10 Groundmen at $2.25	22.50
Total cost per day for gang digging holes	$26.70
1 Lineman at $3.75	3.75
Total cost per day for gang setting poles	$30.45

TABLE V. DIGGING HOLES AND SETTING POLES

DRY EARTH

Poles 40 ft. and over set with derrick.

	Digging holes		Setting poles		
Ht. of pole, ft.	Number per day	Cost per hole	Number per day	Cost per pole	Total labor cost per pole in place
20	45	$0.59	38	$0.80	$1.39
25	45	0.59	31	0.98	1.57
30	36	0.74	26	1.17	1.91
35	36	0.74	23	1.32	2.06
40	32	0.83	29	1.05	1.88
45	29	0.92	25	1.22	2.14
50	25	1.07	22	1.38	2.45
55	21	1.27	19	1.60	2.87
60	18	1.48	14	2.18	3.66
65	14	1.91	9	3.38	5.29
70	11	2.43	8	3.81	6.24
75	9	2.97	7	4.35	7.32
80	8	3.34	6	5.08	8.42
85	7	3.82	5	6.09	9.91
90	6	4.45	4	7.62	12.07

OTHER SOILS

Additional cost digging holes and setting poles over dry earth:

Material	Maximum per cent.	Minimum per cent.	Average per cent.
Hardpan	44.3	36.	40.0
Cemented gravel / Rock	116.5	104.	110.
Wet earth	72.5	68.	70.

NOTE. The above costs do not include any allowance for teaming.

Improved Method of Stenciling Poles. The Telephone Review, Dec., 1914, describes a method and equipment for stenciling poles by which 200 poles may be shaved and stenciled per day. The stenciling outfit consists of a short canvas apron equipped with 5 hooks and 2 pockets. Each hook carries 2 numerals and the

pockets carry a can of stencil paint, an extra can of paint and a rag. The method of holding the stencil has been simplified by placing a hook on one end and a handle on the other. The old and slower method was to strap or tack the stencil to the pole.

As the stencil marking is placed at a height of about 5 ft. and and the usual method is to carry the paint, brush, and stencil plates in a basket which is set at the butt of the pole, it requires for every pole stenciled 10 separate movements of 10 ft. each. For an average day's work using a basket, these long moves introduce about one mile of unnecessary motion.

Labor Costs of Pole-Line Construction. Louis W. Moxey, Jr., in Electrical World, Dec. 18, 1915, gives the following data (Table VI) showing the general range of labor costs for ordinary transmission lines. The labor items vary considerably according to the number of poles to be erected and the amount of wire to be strung.

TABLE VI. LABOR COST OF POLE-LINE CONSTRUCTION

Description	Cost
SHAVING POLES	
25-ft. pole	$0.60 — $1.20
30-ft. pole	0.80 — 1.60
35-ft. pole	1.00 — 2.00
40-ft. pole	1.20 — 2.40
50-ft. pole	1.40 — 2.80
ERECTING WOOD POLES	
25-ft. pole	0.90 — 2.70
30-ft. pole	1.20 — 3.60
35-ft. pole	1.80 — 5.40
40-ft. pole	2.70 — 8.10
50-ft. pole	3.90 — 11.70
ERECTING IRON POLES	
25-ft. pole	2.00 — 8.00
30-ft. pole	3.00 — 12.00
35-ft. pole	5.00 — 20.00
40-ft. pole	8.00 — 32.00
50-ft. pole	12.00 — 48.00
DIGGING HOLES	
25-ft. pole	0.60 — 3.00
30-ft. pole	0.75 — 3.75
35-ft. pole	0.90 — 4.50
40-ft. pole	1.05 — 5.25
50-ft. pole	1.20 — 6.00
STEPPING POLES	
25-ft. pole	0.50 — 1.00
30-ft. pole	0.75 — 1.50
35-ft. pole	1.00 — 2.00
40-ft. pole	1.25 — 2.50
50-ft. pole	1.50 — 3.00
GUYING POLES	
25-ft. pole	3.00 — 9.00
30-ft. pole	4.00 — 12.00
35-ft. pole	5.00 — 15.00
40-ft. pole	6.00 — 18.00
50-ft. pole	7.00 — 21.00
ERECTING CROSS-ARMS, BRACES, PINS AND INSULATORS	
2-pin cross-arm	$0.50 — $1.00
3-pin cross-arm	0.60 — 1.20
4-pin cross-arm	0.70 — 1.40
6-pin cross-arm	0.90 — 1.80
8-pin cross-arm	1.10 — 2.20
STRINGING WIRE, TRIPLE-BRAID, WEATHERPROOF, PER 1000 FT.	
No. 8	$2.50 — $5.00
No. 6	2.60 — 5.20
No. 5	2.80 — 5.60
No. 4	3.10 — 6.20
No. 3	3.50 — 7.00
No. 2	4.00 — 8.00
No. 1	4.60 — 9.20
No. 0	5.20 — 10.40
No. 00	6.00 — 12.00
No. 000	6.90 — 13.80
No. 0000	7.90 — 15.80

Cost of Butt Treatment. The following prices from a bulletin prepared by Page and Hill Co. were current in the spring of 1916.

The height of treatment is about 1.5 ft. above the ground line of poles set at the average depth.

The different types of treatment all require a seasoning of the

TABLE VII. COST OF BUTT TREATMENT

Length of pole, ft.	Diam. of top, ins.	Height of of treatment, ft.	Cost of treatment AA	A	B
			WHITE CEDAR POLES		
20	5	5	$0.35	$0.45	...
25	5	6	0.40	0.55	...
..	6	6	0.70	0.90	$1.30
30	6	7	0.85	1.10	1.85
..	7	7	1.00	1.25	1.95
35	6	7.5	1.05	1.35	2.05
..	7	7.5	1.20	1.50	2.35
			RED CEDAR POLES		
35	8	7.5	1.20	1.50	2.25
40	8	7.5	1.35	1.75	2.50
45	8	8	1.60	2.00	2.75
50	8	8	1.85	2.50	3.00
55	8	8	2.00	3.00	3.75
60	8	8.5	2.50	3.50	4.50

poles for a period of four months. In arriving at a seasoned month, the calendar months are rated as follows:

	Equivalent in seasoning months		Equivalent in seasoning months
January	⅛	July	1
February	⅛	August	1
March	¼	September	1
April	½	October	¾
May	¾	November	⅜
June	1	December	⅛

"AA" and "A" treatments are identical except that in the "AA" treatment creosote is used while in the "A" treatment carbolineum is used. Both treatments are made in open tanks and are for a period of 15 mins. if the temperature is below 70 degs. F. or more. If the temperature is below 70 deg. F. the time of treatment is increased proportionally. During the treatment the bath must be maintained at a temperature of not less than 180 deg. F. nor more than 230 deg. F. and must be heated to a temperature of 215 deg. F. at least once in 4 hrs.

The "B" treatment is done in open tanks using an alternate hot and cold bath of creosote. The hot bath, having a max. temperature of 230 deg. F. and a min. temperature of 180 deg. F., must be heated to 212 deg. F. at least once in every 4 hrs., is for a period of 4 hrs. The cold bath, which must be below 112 deg. F., is then used for a period of 2 hrs.

Cost of Creosoting Poles. R. A. Lundquist in Western Engineering, Jan., 1913, gives following table of costs and quantities of creosote required for butt treatment of various kinds of poles.

Value of Treating Poles and Equipment. In a paper read before the Minnesota Electrical Association, abstracted in Electrical World, May 26, 1916, S. B. Hood of the Minneapolis General Electric Company said, that the average life of a pole which has had a good

Species	Size of pole Top diam., ins.	Size of pole Length, ft.	Amt. cresote applied, lbs. per pole	Cost of treatment c Preservative	Cost of treatment c Total cost
Chestnut	7	30	25	$0.30	$0.75
Northern white cedar	7	30	50	0.60	1.05
Western yellow pine a	8	40	37.5	0.90	1.35
Western yellow pine b	8	40	62.5	1.45	1.90
Western red cedar a.	8	40	39	0.90	1.35
Lodge pole pine......	7	35	35	0.80	1.25

a — 6 lbs. per cu. ft.
b — 10 lbs. per cu. ft.
c — Cost of operation $0.45 per pole.

open-tank treatment with a high-distillate creosote oil will be 20 years, as compared with 8 to 10 years for untreated poles. As an example of the economy of pole treatment, take a 35-ft. pole costing when it is set in position untreated $10 and having a life of 8 years. Compare this with a treated pole costing in position about $11.50 and having at least 20 years of useful life. With interest at 6%, the annual cost for the untreated pole is $1.85 and for the treated pole $1.26, a decrease of nearly one-third in the annual fixed charges.

If the life of the poles is increased, it is necessary to get an equal life from the various pole fittings. In the case of hardware this has been accomplished by using a zinc coating, the hot galvanizing process having been proved the best. For cross-arms an equal life can be obtained by open-tank impregnation similar to that used for the pole butts. The life of the arm as well as its strength can also be increased considerably by using one of the several forms of metal pin which clamp around the arm. Where the cost of these is not warranted metal pins with a small shank may be used. The old-style wood pin, requiring the removal of a large part of the arm to provide a sufficiently large hole, should have no place in modern overhead construction.

For low-tension circuits, principally secondary work, where the maximum voltage does not exceed 750 volts between wires, cross-arm construction should be abandoned entirely for galvanized-steel racks or brackets. These cost less than good cross-arms with their fittings, and there is practically no limit to the useful life that can be had from them. In addition, they make it possible to support the wires in a vertical plane on short centers. In this position there is no tendency for the wires to swing together, and if the circuit carries alternating current the inductive drop is materially reduced by the close spacing. This method of construction permits taking off service drops without using an unsightly buck-arm. The general appearance of a line constructed with these brackets or racks is all that can be desired and should reduce the growing demand for underground construction in congested districts.

Cost of Concrete Bases for Wood Poles. Engineering and Contracting, Aug. 28, 1908, gives the following: Fig. 2 shows a concrete base for transmission line poles invented by M. H. Murray of Bakersfield, Cal., and used by the Power Transit & Light Co.

of that city. These bases are molded and shipped to the work ready for placing. They weigh about 420 lbs. each. One base requires 37.5 lbs. of 2 x 0.25 in. steel bar, 40 lbs. of Portland cement, 3 cu. ft. of broken stone or gravel and enough sand to fill the form or mold, which is 10 x 10 ins. by 4.5 ft. Unskilled labor is employed in the molding and two men can mold ten bases per 8 hr. day. The cost of molding is as follows per base:

2 men at $2 per day	$0.40
Brace irons per set	2.50
1/9 cu. yd. stone at $4.05	0.45
40 lbs. cement at 1.5 cts.	0.60
Sand	0.15
Total cost	$4.10

In the work for the company named above two men at $2 per day each set 5 bases in 8 hrs., making the cost of setting 80 cts. per base. The bases were sunk to a depth of 3 ft. 3 ins. In many

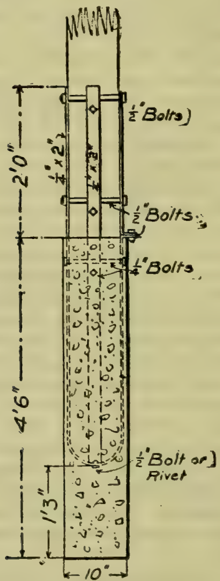


Fig. 2. Concrete base for wooden poles.

cases they were placed under poles without interrupting service by sawing off the pole, dropping it into the ground, placing the new base and setting the sawed-off pole on it and bolting up the straps.

Cost of Reinforcing Wood Poles with Concrete. Red-Cedar poles which had been in service for nearly 17 years were recently reinforced with concrete by the Puget Sound Traction, Light & Power Company. The line is 7 miles long and is a main power line serving the American Smelting & Refining Company's plant at Tacoma, Wash. The following costs are given in Electrical World, May 19, 1917.

First the earth around the ground line was removed. Then iron rods with the ends bent at right angles were driven into the poles around the weakened section and expanded-metal strips wrapped around the rods. After a piece of sheet metal had been placed inside the hole around the pole butt to serve as a form the concrete was poured. About 7 rods were used on each pole. The cost of reinforcing the 259 poles on this line cost was $2,355.14, making the total cost per pole $9.10 and the material cost per pole $3.59. The following table gives the unit amount of each kind of material used, and the cost thereof as well as the labor cost.

	Cost per pole
Material:	
6.1 No. 1 iron rods	$1.40
1.7 No. 2 iron rods	0.49
1.16 expanded metal	0.246
0.21 cu. yds. sand	0.304
0.38 cu. yds. pea gravel	0.612
1.83 sacks cement	0.933
Tools, etc.	0.633
Labor:	
Hauling (including rent of wagon)	0.71
Reinforcing	3.59
Moving poles	0.05
Guying	0.042
Cleaning up	0.05
Miscellaneous	0.043
Total	$9.10

Concrete Settings for Wooden Poles. We quote the following communication from Page & Hill Co. in regard to concrete settings for wooden poles.

"A careful examination following the storms (Autumn of 1915) at Houston showed that most of the poles that went down were set in concrete. The same condition was observed a few years ago after a severe storm at Fargo, N. D.

"This would tend to show that a concrete setting adds nothing to the strength of a wooden pole.

"There is no preserving value in a concrete setting. In fact, the concrete may hasten decay by retaining the moisture in the wood, thereby creating the most favorable conditions for the growth of the wood-destroying fungi."

Joint Pole Construction at Los Angeles, Calif. J. E. MacDonald in the Transactions of the A. I. E. E., April, 1912, gives a series of curves, Fig. 3, showing the market prices of poles at tidewater points, from which points distribution is made locally. Supplementing this, is the curve showing the valuations according to the

joint schedule for new poles set, painted and stepped. It will be noted that this gives a valuation of 35 cts. per pole foot for poles 30 to 60 ft. in length. Poles which have been set less than 3 years are assumed to be of the same value as new poles. Poles set from 3 to 6 years are assumed to be of the same value as new poles, but no value is given to that portion of the pole which is in the ground.

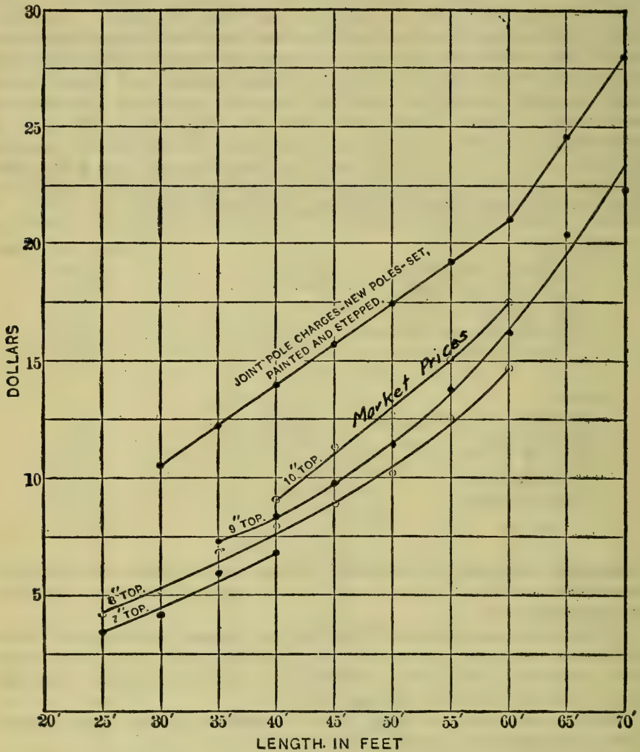


Fig. 3. Joint pole charges and market prices of round cedar poles.

Poles set over 6 years are assumed to depreciate at the rate of 3.5 cts. per ft. per annum, but no value is given to that portion of pole which is in the ground. During 5 years' operation under this schedule, it has been found that the valuations are approximately correct. The values given for 50 ft., 55 ft. and 60 ft. poles are lower than they should be, but inasmuch as such poles are usually set by the party desiring the top position and the added length is

often solely for this party's benefit, it has not been found that the charges prove inequitable.

During the 5 years under discussion no individual, save a newspaper reporter, has precipitated the query "Does it pay?" It should not be necessary to furnish exact data on this point. The reduction in investment, that is, the difference between the purchase and installation cost of over 50,000 poles independently and operated, as against 21,270 combination poles, is subject to exact deduction. The difference in the maintenance and depreciation charges on them represents a quantity which may also be arrived at very closely. The saving in the maintenance and depreciation charges, at joint expense, of the combination poles for one year exceeds the cost of maintaining the office of the committee for the entire period of 5 years. In addition to this there are the intangible quantities, such as the saving which results from such a project as a matter of public policy; also the saving due to the entire absence of accidents on joint poles, on account of superior construction. Some of us might even figure on the conservation possibilities, taking the entire United States as a basis of action.

Cost of Setting Wood Poles. Tables VIII and IX give the estimated cost of setting poles, taken from "Data."

TABLE VIII. COST OF SETTING WOOD POLES, AVERAGE CHICAGO CONDITIONS (1900–1910)

Length, ft.	Top, ins.	Cost in rough	Shaving, etc.	Hauling	Setting	Painting	Paint	Total cost †
10	8	$0.75	$0.40	$0.30	$2.50	$0.20	$0.08	$4.23
15	8	1.00	.50	.30	2.50	.20	.08	4.58
20	8	1.25	.60	.35	3.00	.24	.10	5.54
25	6	1.98	.90	.395	3.24	.31	.16	6.99
25	7	2.72	.90	.395	3.24	.31	.16	7.73
25	8	4.00	.90	.395	3.24	.31	.16	9.01
30	6	3.06	1.10	.450	3.50	.35	.16	8.62
30	7	5.00	1.10	.450	3.50	.35	.20	10.60
30	8	6.25	1.10	.450	3.50	.35	.20	11.85
35	7	8.00	1.30	.481	3.75	.42	.20	14.15
35	8	8.10	1.30	.481	3.80	.42	.24	14.34
40	7	9.10	1.55	.600	4.25	.50	.24	16.24
40	8	10.05	1.55	.600	4.38	.50	.28	17.36
45	7	11.81	1.80	.640	5.10	.58	.28	20.21
45	8	14.00	1.80	.640	5.25	.58	.28	22.55
50	7	13.43	2.10	.750	6.50	.64	.33	23.75
50	8	15.57	2.10	.750	6.70	.64	.33	26.09
55	7	16.00	2.30	.869	8.62	.72	.38	28.89
55	8	21.00	2.30	.869	8.90	.72	.38	34.17
60	7	22.00	2.75	.948	9.41	.80	.44	36.35
65	8	27.07	3.10	.980	10.19	.88	.52	42.74
70	7	35.00	3.40	1.050	10.97	.96	.60	51.98

Foreman's wages included. † No supervision or other overhead charges included.

Table IX is from the Valuation Report of the Calumet Electric Street Ry. Co. and South Chicago Ry. Co. as prepared by the Traction Valuation Commission, Chicago.

TABLE IX. COST OF SETTING WOOD POLES, CHICAGO TRACTION VALUATION COMMISSION (1911)

Length ft.	Diam. top ins.	Price of pole	Cost of labor	Total cost in place for different settings: Heeled and breasted	Set in barrels	Set in rock	In 1 cu. yd. concrete
30	7	$5.20	$2.80	$8.75	$9.50	$10.00	$11.50
35	7	8.10	2.90	11.75	12.00	13.00	14.50
40	8	11.45	3.05	15.20	15.50	16.50	18.00
45	8	15.10	3.25	19.10	19.35	20.35	21.85
50	8	15.40	3.60	19.75	20.00	21.00	22.50
55	8	17.60	4.00	22.35	22.60	23.60	25.10

Cost of Setting Chestnut Poles. As an example of the basis for computing the costs of pole setting, a member of the Ohio Electric Light Association furnished the following data given in Electrical World, Feb. 24, 1917.

The costs given are for 2 lines built through a hilly country. The poles used are chestnut and vary in length from 45 ft. to 60 ft. The average length of the poles was 48 ft.

Number of poles	328	485
Labor per pole (hauling, trimming, setting and cross-arming)	$18.78	$15.88
Extra teaming (hauling men and material)	2.59	2.86
Miscellaneous	1.10	4.43
Insurance	.95	.78

"It will be noted that the miscellaneous charges in the second column of the table are rather high. This is due to the many incidentals that happen in the building of any transmission line occasioned by unforeseen difficulties, of damages and other difficulties that impede construction work. These figures are meaningless to anyone not familiar with the type of construction. Chestnut poles of class 'A' specifications were used, which are nearer sawlogs than they are poles. Each pole was equipped with an angle-iron bayonet and with 2 wood crossarms 4 in. by 5 in. by 8 ft. These in turn were equipped with three strings of suspension insulators 5 units per string."

Rapid Erection of 50-Ft. Cedar Poles. Electrical World, April 7, 1917, gives the following data on setting poles by the use of a Matthews pole erector. The San Diego, Cal., Consolidated Gas and Electric Company has been able to raise poles on 3 transmission lines in an average time of 12 mins. per pole. One line consisted of an 18-mile stretch of 66,000 volt circuit, and the other two were 11,000 volt circuits, 12 miles and 16 miles long respectively. Most of the poles were 50 ft. Western red cedar, with not less than 9 in. tops and an average weight of 1600 lbs. each. In some places 55 ft. and 60 ft. poles were used. All of the lines stretch across rough, brush-covered country.

The equipment which was used consisted of a Matthews pole erector with an extension built on the peak of the gin. It was found necessary to increase the effective height of the gin because of the 55 ft. and 60 ft. poles, which had to be raised occasionally, and because, in rough country, it is not always possible to place

the bed of the pole-erector wagon on a level site and thus obtain the advantage of the full normal height of the gin. At first the increased height was obtained by putting a channel-iron extension on the peak of the gin. Later, when this extension was bent, it was replaced by another made from two pieces of Douglas fir measuring 3.75 ins. by 5.75 ins. by 10 ft.

Experience with this outfit has shown that it is advisable to haul the pole-erector wagon with a team and to use an automobile truck for pulling the rope. Where the earth is soft the wagon has to be blocked up so that the feet of the erector will have a solid bearing. In speaking of the use of this apparatus under severe conditions in rough country, L. M. Klauber, superintendent of the electrical department for the San Diego company, pointed out that even on the first day this outfit was used the line crew required an average of only 13 mins. from pole to pole, including the time consumed in setting the erector and in traveling from hole to hole. The pole spacing was 350 ft.

The pole erector was made by W. N. Matthews & Bro., of St. Louis.

Cost of Setting Poles by Block and Tackle. E. B. Hook, superintendent of construction, Georgia Railway & Power Co., gives the following data in Electrical World, Feb. 24, 1917.

We have set quite a number of poles in north Georgia during the past few years, and by using a block and tackle method of our own design have been able to set a large number of 50 ft. creosoted poles in a day's time with a minimum number of men at a cost of 60 cts. to 75 cts. per pole. This figure, of course, does not include anything but actually setting and tamping in the poles. The cost of compiling the figures is negligible, as it required merely the scanning of a few daily field reports selected at random. We have used the block and tackle method for a couple of years and employed a pair of mules and 9 or 10 men to set poles. Recently a 1.5 ton truck has been substituted for the mules and the services of 6 or 7 men dispensed with. In other words, we are now setting from 25 to forty 50 ft. and 60 ft. creosoted poles, weighing approximately 2 tons each, in a day with 3 men and the truck at a cost which is approximately 33 cts. per pole.

Cost of Chestnut Poles and Pole Line. The report of the Board of Public Utility Commissioners of New Jersey on the application of the Jersey Power Company to issue capital stock, abstracted in Electrical World, Aug. 8, 1914, states that, the contract with the Hopatcong Mountain Lake Land Development Company for 516 poles showed the following prices: Six 70 ft. long at $18.50 each; ten of 65 ft. at $15 each; fifty of 60 ft. at $11.50; eighty of 55 ft. at $8.75; 120 of 50 ft. at $8; 250 of 45 ft. at $5.50. The average price was $7.50; the average height was 49 ft.

The cost of poles from Boonton to Millbrook, N. J., is figured by the commission at $2,660. This allows for 406 poles with a total of 19,250 ft., or an average of 47.3 ft. and an average price of $6.55 per pole. This estimate is based on an average number of 45 poles per mile. The commission's engineer, H. E. Carver, testi-

fied that in his judgment $4.10 was an adequate price for setting a pole. The engineer for the company, Mr. Lowe, testified that the cost of stringing wire would average about $25 per mile of wire. The commission allowed $45 per mile for stringing wire from Millbrook to Dover owing to the conditions under which this wire must be strung.

In general, on the figures of the company the commission estimated the average price of poles delivered on the cars at $7.50 each. It allowed on the basis of the evidence $7.50 as the average cost for unloading, teaming, hauling, digging, locating, framing, setting and tree-trimming, including necessary guys and anchors for poles. The commission allowed for wire 5% more than the estimate of the company inasmuch as the estimate allowed nothing for sag. For braces, insulators and cross-arms on poles the commission allowed only $7 between Boonton and Millbrook. To the total net cost of physical construction, as estimated, the commission added 13% for engineering and contingencies. The testimony as to the cost of right-of-way showed an outlay of roughly $8,000 therefor.

Detail Cost of Cross-Arms. The following is taken from cost data compiled by Mr. Burroughs, engineer of Washington State Commission.

Placing Arms. One line man at $3.75 per day will tack on from 20 to 30 6-pin arms in one day. Considering 25 as an average, the cost would be 11 cts. each. An average of fifteen 10- and 16-pin arms can be placed at a cost of 25 cts. each.

Fitting up Arms. One man at 35 cts. per hr. can fit up 10 10-pin arms per hr., a cost of 3.5 cts. each. On this basis a 6-pin would

TABLE X. SINGLE CROSS ARM PRICES

Material	6 pin	10 pin	16 pin	10 knob	20 knob	Back brace	Extra brace
Cross arm	$0.30	$0.43	$0.44	$0.30	$0.30	....	....
2 30-in. braces	.18	.18	.18	.18	.18	....	$0.18
1 machine bolt, 5/8 ins. by 12 ins.	.05	.05	.05	.05	.05	....	....
2 car bolts 3/8 ins. by 4 ins.	.02	.02	.02	.02	.02	....	.02
1 lag screw 1/2-in. by 4 1/2 ins.	.01	.01	.01	.01	.02	....	....
Locust pins 1 1/4 ins. by 8 ins.	.09	.14	.23	....	....	....	....
No. 4 knobs	...	....	....	.05	.10	....	....
3-in. No. 15 screws	...	....	....	.03	.06	....	....
1 angle iron back brace	...	....	....	....	....	$0.09	....
4 machine bolts 1/2-in. by 4 1/2 ins.	...	....	....	....	....	.09	....
	$0.65	$0.83	$0.93	$0.64	$0.73	$0.99	$0.20
Labor							
Fitting up arms	$0.03	$0.04	$0.05	$0.08	$0.10	....	....
Distributing arms	.03	.03	.03	.03	.03	....	....
Placing arms	.11	.25	.25	.25	.25	$0.35	$0.15
	$0.17	$0.32	$0.33	$0.36	$0.38	$0.35	$0.15
Total cost	$0.82	$1.15	$1.26	$1.00	$1.11	$1.34	$0.35

TABLE XI. DOUBLE CROSS ARM PRICES

Material	6 pin	10 pin	16 pin	10 knob	20 knob
2 cross arms	$0.60	$0.86	$0.88	$0.60	$0.60
4 30-in. braces	.36	.36	.36	.36	.36
1 ⅝-in. by 18-in. machine bolt	.08	.08	.08	.08	.08
4 ⅜-in. by 4-in. car bolts	.04	.04	.04	.04	.04
4 ⅝-in. by 18-in. double arm bolt	.24	.48	.48	.48	.48
2 ½-in. by 4 ½-in. lag screws	.03	.03	.03	.03	.03
1 ¼ by 8-in. locust pins	.17	.28	.45	..	..
Knobs	..	..	..	.10	.20
Screws	..	..	..	.06	.12
	$1.52	$2.13	$2.32	$1.75	$1.91
Labor					
Fitting up arms	$0.08	$0.12	$0.14	$0.20	$0.25
Distributing arms	.04	.04	.04	.04	.04
Placing arms	.37	.65	.65	.65	.65
	$0.49	$0.81	$0.83	$0.89	$0.94
Total cost	$2.01	$2.94	$3.15	$2.64	$2.85

cost 2.5 cts. and a 16-pin 4.5 cts. Placing knobs will cost at least 7.5 cts. for a 10-knob and 10 cts. for a 20-knob.

Distribution. A team at $6 and a ground man at $2.50 (a total charge of $8.50 per day) will distribute all the arms that an ordinary gang can use. Hence the cost of distributing will depend entirely upon the number used. Considering a 10-man gang as placing 200 arms per day, and this team and ground man requiring one-half day to load and distribute them, the cost will be 2.1 cts.

Creosoted. Creosoting will cost 13 cts. for a 10-pin and 14 cts. for a 16-pin arm. These prices are based on a cost of $15 per M. ft. b. m. for creosoting lumber.

Brackets. Cost of oak bracket 1.5 cts.; cost of spikes, 1 ct.; labor, considering 15 brackets placed per hour, 3 cts.; making a total 5.5 cts.

Labor Cost of Stringing Guys. The data given in the following table were obtained in connection with an appraisal on the Pacific Coast.

LABOR COST OF STRINGING GUYS

Class	Size	Guys per day	Cost per guy	Average length, ft.	Cost per ft.
Head or stub	#8 galv. iron ¼-in. g. i.	9	$1.11	163	$0.0068
Head or stub	⅜-in. g. i.	6	1.66	160	0.0104
Anchor	#8 g. i. ¼-in. g. i.	8	1.25	39	0.0321
Anchor	⅜-in. g. i.	5	2.00	58	0.0345
Bridle Guy	⅜-in. g. i.	4	2.50	75	0.0333

In the above table the cost per guy is based upon the average number of guys placed per day by the following gang:

2 linemen at $3.75 per day	$7.50
1 groundman at $2.50 per day	2.50
Total labor cost per day	$10.00

Detail Cost of Single Anchor Guys. The following costs are taken from a recent Pacific Coast appraisal.

Digging holes at $1.98 each:	
6 laborers, 8 hrs. at 30 cts. dig 8 holes at a cost of	$14.40
Add 10% for foreman's wages	1.44
Cost of 8 holes	$15.84
Placing and refilling at $1.11 each:	
1 man, 8 hrs. at 50 cts.	$ 4.00
3 laborers, 8 hrs. at 30 cts.	7.20
Place and refill 11 holes at a cost of	$11.20
Add 10% for foreman's wages	1.12
Cost for 11 holes	$12.32
Placing strand at $0.93 each:	
4 linemen, 8 hrs. at 50 cts.	$16.00
2 helpers, 8 hrs. at 30 cts.	4.80
Place 24 guy strands at a cost of	$20.80
Add 10% for foreman's wages	2.08
Cost for 24 guy strands	$22.88

The average cost for teaming is approximately $0.25 per guy.

The average cost of tying in an insulator is $0.07.

Cost of Anchor Logs and Guys. The following data are from a recent Pacific Coast appraisal.

Anchor logs are frequently made from old poles cut in 6 to 8 ft. lengths. Two men will cut, dig holes for and place one such anchor log in about 5 hrs. Two linemen will place a single guy in 1 hr. and a double guy in 2 hrs. An iron wire guy takes 2 men about .5 hr. to complete. Comparative costs are as follows:

COST OF ANCHOR LOGS AND GUYS

	Single guy	Double guy	Wire guy
Cutting anchor log, 6 ft. at 7 cts.	$0.42	$0.42	....
Digging holes and placing log, 10 hrs. at 25 cts.	2.50	2.50	....
Teaming	.25	.25	$0.10
Placing strand	1.00	2.00	.50
Cost complete	$4.17	$5.17	$0.60

Detail Cost of a 50 Ft. Single Anchor Guy. The following is from a recent Pacific Coast appraisal.

	Cost
50 ft. of 5/16-in. strand, at $0.14	$0.57
2 guy hooks, at $0.06	.12
1 bolt 5/8 ins. by 12 ins.	.05
1 thimble	.02
2-3 bolt clamps at $0.123	.25
2 strain plates, 4 by 8 ins. at $0.042	.08
Nails	.01
Total cost of 5/16-in. guy complete	$1.10

For ⅜-in. strand add	$0.55
Total cost of ⅜-in. guy complete	$1.65
For 7/16-in. strand add	$0.60
Total cost of 7/16-in. guy complete	$2.25
For a double guy, add another clamp and an extra thimble, a total of	$0.14

And in addition, for strand:

5/16-in.: 45 ft. x $0.0114 = $0.51
6/16-in.: 45 ft. x $0.0223 = $1.00
7/16-in.: 45 ft. x $0.0342 = $1.54

TABLE XII. COST OF SINGLE HEAD GUYS 145 FT. LONG

	5/16-in. strand	⅜-in. strand	7/16-in. strand
Strand, 145 ft. long	1.65	3.23	4.96
Guy hooks	$0.12	$0.12	$0.12
Machine bolts	.05	.05	.05
Guy clamps	.25	.25	.25
Strain plates	.17	.17	.17
Nails	.01	.01	.01
	$2.25	$3.83	$5.56

Iron wire 145 ft. long costs for No. 6, $0.57 and for No. 9, $0.30.

Cost of Head Guys. The following is from a recent Pacific Coast appraisal.

Two men and a helper will place 3 head guys in 2 hrs. The following are costs for insulated and uninsulated head guys.

	Insulated guy	Uninsulated guy
72 ft. of ⅜-in. strand at $0.012	$0.86	$0.86
1 wood insulator	.23	....
Placing strand	.95	.95
Distributing	.10	.10
Tying in insulator, each	.07	....
Cost, complete	$2.21	$1.91

Concrete Poles. The principal advantages of concrete poles are greater strength and length of life. The principal disadvantages are difficulty in setting due to weight, greater first cost, although in many cases the annual cost of concrete poles is less than for wood, and in some cases the first cost is even lower than for wood poles of equal strength. Another disadvantage claimed by exponents of the wooden pole is that a lineman working on the wires on a concrete pole is grounded, which is not the case on a wood pole.

However, due to the greater durability of the concrete pole, its greater reliability in times of severe stress and the constantly increasing cost of wood poles, the concrete pole is often to be preferred.

Cost of 30 Ft. Concrete Poles. The following is abstracted from a letter by F. S. Hunt to Engineering & Contracting, Feb. 26, 1908.

The prime factors in the construction of concrete poles are the materials forming the grout. Unless the best quality of crushed stone and sand is used, desired results cannot be obtained.

The steel reinforcing rods are placed 1 in. from the surface of the pole in 3 sets; 4 rods extend to the top of the pole, 4 rods two-thirds of the length of the pole and 4 rods one-third of the length. In testing the finished pole to destruction this distribution of the steel was found to be practical, giving a uniform stress from top to ground line. A 30 ft. pole with 6 in. top and 9 in. base deflected 3 ft. at the top from a plumb line, and straightened when the load was removed without any apparent damage to the pole. A 30 ft. pole must stand a strain of 2,500 ft. lbs. at the groundline. The feature to be reckoned with in the building of a line of concrete poles is the transportation and erection. A 30 ft. pole, with a 6 in. top, will weigh 2,000 lbs. It is a practical proposition to build this length pole in a yard, in forms on the ground. A pole of any greater length should be built in place, from the ground up, although there have been erected 45 ft. poles that weighed 5,600 lbs. The 30 ft. reinforced concrete pole can be built in Chicago for $7.50 and erected with proper equipment for $1 each.

The reinforced 30 ft. concrete pole with 6 in. top and 10 in. base, and corners chamfered to 1 in. radii contains .5 cu. yd. of concrete and 200 lbs. of steel, the cost being as follows:

200 lbs. of steel at $1.85 per 100 lbs.	$3.70
½ cu. yd. concrete at $7.50 per yd.	3.75
Total	$7.45

The estimate of the cost of the finished pole is based on the following prices: Crushed stone $1.25 per cu. yd., sand $1.10 per cu. yd., cement $1.75 per bbl., and labor 20 cts. per hr.

Reinforced-Concrete Poles. J. G. Jackson in Electrical World, Jan. 17, 1914, gives the following. Perhaps the largest installation of concrete poles is that of 25,000 poles installed in connection with the municipal street lighting and general light and power distribution system of the Toronto Hydro-Electric System in Toronto, Canada.

In the design and construction of the poles employed in this installation an effort was made to eliminate unnecessary details and to render the manufacture as simple as possible in order that poles might be turned out rapidly and at low cost. A pole of solid square cross-section with beveled edges was adopted. As the majority of these poles were intended to carry an ornamental lighting bracket and tungsten lamp, they were provided with a .5 in. iron pipe cast in the pole with lower outlet at the lamp and upper outlet under the line wires.

The earlier poles of the installation were provided with three galvanized-steel cross-arms cast to the pole and having a hole at each end for a steel core pin. This arrangement of cross-arms was not found sufficiently flexible in obtaining clearances of the lines and was later discarded. Holes were provided through the pole

with a slot on either face so that brackets of any desired length could be bolted to the pole.

The poles ranged from 24 ft. to 35 ft. in length, the majority being 24 ft. long. Standard poles were made with 8-in. by 8-in. base and 5-in. by 5-in. top, for 24 ft. poles, with 9-in. by 9-in. base and 6-in. by 6-in. top for 30 ft. poles, and with 10-in. by 10-in. base and 6-in. by 6.5-in. top for 35 ft. poles. The longitudinal reinforcement consisted of four deformed or square twisted steel bars of high elastic limit set at the corners of the pole and 0.5 in. from the surface. Three-eighth-in. bars were used in the 24-ft. poles and 0.5 in. bars in the longer ones.

The plant employed in the manufacture of these poles consisted in the main of parallel horizontal forms arranged in rows with a runway at one end of the forms for the delivery of concrete, together with concrete mixer and special wagons for placing the concrete in the poles. All forms were constructed of finished Southern pine, as more satisfactory results were obtained with this wood than with the less dense and resinous Northern variety. Bases of forms were spaced 2 ft. apart with wooden rails between, one pair of sides being provided for each three bases. A very wet mixture of concrete in the proportions of one part cement to two parts of sharp sand and four parts of crushed limestone of less than 0.5-in. size was used. The quality of sand used was found to have an appreciable effect on the characteristics of the pole, a sharp sand, as would be expected, tending to produce the more elastic concrete. Gravel instead of crushed stone was found to give satisfactory results.

In casting the poles, sides were set up and forms poured on every third base during the first day. On the following day the side walls were removed from the first poles and advanced to the second base, and the operation was repeated. On the fourth day the first poles cast were removed from the forms and the cycle of operations was started again. The removal of poles from the forms was accomplished by sliding the pole endwise from the form in stages a distance slightly greater than its length every third day, until sufficiently set for handling.

Vertical reinforcement was placed by laying it in the form on wire hangers suitably spaced and with open hooked portions to carry the reinforcing bars. The lateral reinforcement intended to take up the vertical shear and to prevent failure by buckling consisted of a series of short bars with hooked ends dropped diagonally across the longitudinal members at intervals and for a distance above and below the ground line proportioned to the strain to be provided for. No effort was made to bind the longitudinal reinforcement in a cage by means of the suspension wires or together by means of the cross-reinforcing bars except by hooking together as noted and depending on the setting of the concrete to complete the bond, and lock the reinforcement in place.

Cost of Concrete Electric Railway Trolley Poles. The Fort Wayne & Wabash Valley Traction Co., operating some 150 miles of street and interurban trolley line, proposes to make its renewals

TABLE XIII. COST OF STREET-LIGHTING POLES DESIGNED TO CARRY SIX WIRES AND ORNAMENTAL TUNGSTEN-LAMP BRACKET WITH CONDUIT CONNECTION

24-ft. pole, 8-in. by 8-in. base, 5-in. by 5-in. top; volume of concrete, 7 cu. ft.

Cement, at 40 cents per bag	$0.70
Stone, at $1.33 per ton	0.40
Sand, at $1.15 per cu. yd.	0.15
⅜-in. steel reinforcing bars, at $1.95	0.89
Suspensions for reinforcing bars	0.06
Lateral reinforcing bars	0.10
½-inch pipe and fittings	0.27
Three galvanized-steel cross-arms	0.26
Miscellaneous material	0.05
Depreciation of forms	0.40
Mixer and other plant	0.12
Preparing yard	0.08
Total	$3.48
Labor	1.05
Total labor and material, etc.	$4.53
Adding for engineering supervision, office expenses, 10%	0.45
Total	$4.98*

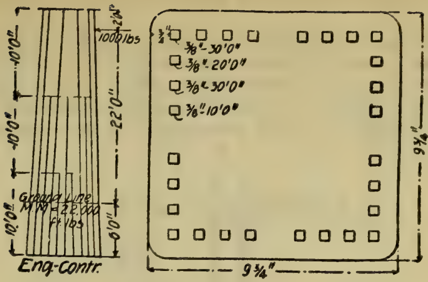
30-ft. pole, 9-in. by 9-in. base, 6-in. by 6-in. top; volume of concrete 12 cu. ft.

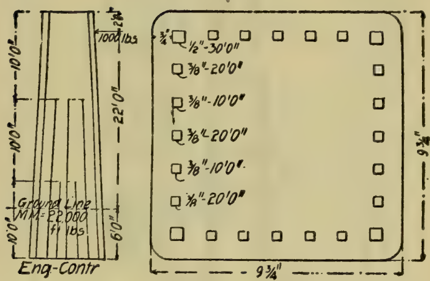
Cement	$1.20
Stone	0.71
Sand	0.26
½-in. steel bars, at $1.85	1.89
Suspensions	0.07
Lateral reinforcing bars	0.14
½-inch pipe and fittings	0.43
Galvanized cross-arms	0.26
Miscellaneous	0.06
Forms	0.50
Mixer and other plant	0.12
Yard	0.08
Total	$5.72
Labor	1.31
Plus 10%	0.70
Total cost	$7.73*

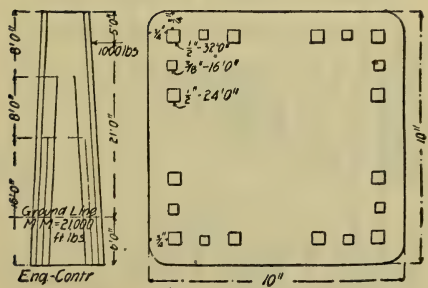
* This includes the iron conduit pipe and galvanized steel cross-arms, so that the cost of a plain 24-ft. pole would be $4.39 and that of a plain 30-ft. pole would be $6.97.

with concrete poles of the construction shown by Figs. 4 to 7. The weight and dimensions of the pole and the bill of material required are given for each size. Regarding the construction of these poles H. L. Weber, chief engineer of the road, writes:

"The cost of constructing concrete poles depends so much upon the location of the materials with respect to the points where the poles are to be erected that general figures are difficult to state. Having several good gravel banks at convenient points along our right of way, which is 120 miles in length, and having our road already built and the equipment available for handling materials







Figs. 4-5-6.

Fig. 4. Trolley pole 42 ft. long.
Fig. 5. Trolley pole 32 ft. long.
Fig. 6. Trolley pole 30 ft. long.

and poles, we have been able to build concrete poles for about the same cost as a wooden pole all fitted up and painted. We figure that a 33-ft. pole costs $7.50 and a 45-ft. pole costs $15, at pit. It is difficult to figure the cost of molds, as one mold should be good for a number of poles, depending on the care that is taken of it.

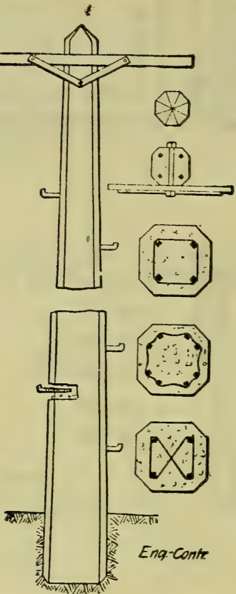


Fig. 7. Concrete telephone pole.

BILL OF MATERIAL, 42 FT. POLE

Item	Lbs.
4 pcs. ¾-in. x 42 ft. twisted steel bar	321.2
8 pcs. ½-in. x 32 ft. twisted steel bar	217.6
8 pcs. ⅜-in. x 16 ft. twisted steel bar	61.2
20 pcs., total weight of steel	600.0
Concrete, 237 cu. ft., weight	3,030.0
Approximate weight of pole	3,630.0
Surface area of steel	14,176 sq. in.
Base area of steel	5,375 sq. in.

BILL OF MATERIAL, 32 FT. POLE

Item	Lbs.
12 pcs. ⅜-in. x 30-ft. twisted steel bar	172.0
8 pcs. ⅜-in. x 20 ft. twisted steel bar	76.6
8 pcs. ⅜-in. x 10 ft. twisted steel bar	38.3
28 pcs. total weight of steel	286.9
Concrete, 13.7 cu. ft.	1,758.0
Approximate weight of pole	2,044.9
Surface area of steel	10,800.0 sq. in.
Base area of steel	3.93 sq. in.

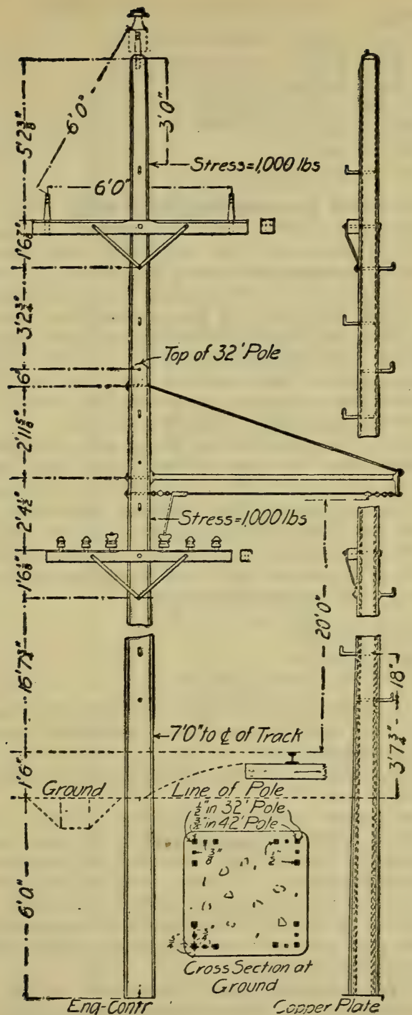


Fig. 8, Concrete trolley pole.

BILL OF MATERIAL, 30 FT. POLE

Item	Lbs.
4 pcs. ½-in. x 30-ft. twisted steel bar	102.0
12 pcs. ⅜-in. x 20 ft. twisted steel bar	114.7
8 pcs. ⅜-in. x 10-ft. twisted steel bar	38.3
24 pcs., total weight of steel	255.0
Concrete, 13.7 cu. ft., weight	1,758.0
Approximate weight of pole	2,013.0
Surface area of steel	10,560 sq. in.
Base area of steel	3,812 sq. in.

No records of cost were kept.

Cost of Reinforced Concrete Telephone Poles. (Engineering-Contracting, March 11, 1908.) The possibilities for reinforced concrete poles in transmission line work were very carefully investigated by the Richmond, Ind., Home Telephone Co., which has constructed a line across the Whitewater River, using poles ranging from 45 to 55 ft. in height of the construction shown by Fig. 8, invented by Wm. M. Bailey, vice-president and general manager of the company. The following account of these investigations and of the studies made by the American Concrete Pole Co., Richmond, Ind., which has been organized to market the poles, has been compiled from information given us by Mr. Bailey.

For poles 30 ft. long and under, the molding is done horizontally on the ground and the pole erected when hard like a wooden pole; for poles over 30 ft. long the molding is done in forms set vertical in the pole hole. The following figures, Table XIV, are given as the cost without royalty of concrete poles molded as described. These costs are for poles erected, excluding the material cost of steps but including labor cost of setting steps, and they are based on the following wages and prices:

Foreman, per day	$3.00
Laborers, per day	1.75
Cement, per barrel	2.00
Stone, gravel or sand, per cu. yd.	1.00

For sake of comparison, the cost of cedar poles has been added to the table; these costs include poles, unloading, dressing, gaining, roofing, boring, hauling and setting. All figures are as furnished by Mr. Bailey. Regarding the methods of constructing concrete poles, Mr. Bailey says:

"All of the larger concrete poles (that is, poles over 30 ft. in height) are built upright in position ready for use, the forms being set perpendicularly over the hole in which the pole is to be placed, the hole having been dug to conform with the size pole prior to the setting of form; thus when the concrete is poured in at the top of form, the hole is entirely filled and the concrete knit firmly to the solid earth that has never been disturbed. There is no replacing of earth or tamping required."

Cost of 35 Ft. Concrete Poles. Electrical World, Nov. 2, 1912, gives the following: The 800-kw. water-power plant of the Rocky Ford Power Company is connected to the Manhattan (Kan.) Ice, Light & Power Company's plant by a 6-mile transmission line using concrete poles. These 35-ft. structures are rectangular in

TABLE XIV. COMPARATIVE COST OF REINFORCED CONCRETE AND CEDAR POLES

	Concrete poles									Cedar poles			
											Cost		
Lgth., ft.	Top, ins.	Bottom, ins.	Size steel, ins.	Cu. ft. conc.	Cost of steel	Cost of concrete	Cost of bind., W.	Labor	Total cost	Top, ins.	F.o.b. cars	Labor	Total
25	6	10	¼	16	$1.57½	$2.24	$1.20	$1.70	$6.71½	7	$2.60	$1.50	$4.10
30	6	11	⅜	21	2.29	2.94	1.20	2.20	8.63	7	6.25	2.00	8.25
35	6	12	½	26	3.91½	3.64	1.20	2.70	11.45½	7	8.75	2.40	11.15
40	7	15	⅝	36	6.31	5.04	1.50	4.20	17.05	8	12.00	3.50	15.50
45	7	16	⅞	43	8.56	6.02	1.50	5.70	21.78	8	17.20	5.00	22.20
50	7	17	⅞	50	9.50	7.00	1.80	7.20	25.50	8	20.20	6.50	26.70
55	7	18	1	56	13.34	7.84	1.80	8.95	31.93	8	24.80	8.50	33.30
60	7	19	1	61	14.56	8.54	1.80	11.70	36.60	8	29.75	10.00	39.75

section, with 45-deg. corners to prevent cracking, and measure 15 in. at the base and 7 in. at the top. They are set at 260-ft. intervals. The solid concrete is reinforced by four .75-in. steel rods. Four-by-four-inch galvanized .1875-in. angle-arms are used, carrying cast-iron pins through-bolted in place. The braces are formed of single, specially bent angles of smaller section. Built in a central yard after some experimentation, these 120 poles cost $22 each. They were hauled to their sites and erected with gin poles at a cost of $5 additional per pole, considerable unforeseen difficulty having been experienced in transporting the heavy structures through the soft marsh-land which the line traverses. After 3 years' service the line gives every evidence of complete durability and satisfaction.

Cost of Manufacturing Reinforced Concrete Trolley Poles. During the season of 1910 the Syracuse Rapid Transit Railway Company manufactured 100 reinforced concrete poles. An analysis of the cost of construction of this class of pole was given in Engineering Record, June 24, 1911, as follows:

The standard 30-ft. concrete pole is reinforced with four .625-in. twisted steel rods 29 ft. 6 in. long, one placed near each corner; four .5-in. twisted rods 29 ft. 6 in. long, one placed in each side of the pole and four .5-in. twisted rods 18 ft. long extending from the butt upward, one on each side of the pole between the other rods. The butt of the pole measures 11 in. square and the top 6 in. square, a .625-in. hole being cast in the pole 3 ft. below the top for the span-wire eye-bolt and a cross-arm gain 12 in. below the top for a feeder-cable cross-arm. The corners of the pole are given a 2-in. bevel extending from the top of the pole to within 6 ft. of the butt. The concrete mixture is formed from one part Portland cement and two parts sand and two parts .375 to .75-in. broken stone.

The unit cost for one pole, taken from the total cost for a lot of fifty, including all labor and material except cost of forms and installation of plant, was: Labor, $2.81; material, $7.04; total, $9.85.

The forms built were of hard pine 2 in. thick and cost $19.16 each.

The cost of installing the plant, including derrick, concrete casting sills and cement shed with pump, etc., was $401.96.

It is expected that the forms will suffice for the casting of 50 poles each, without much repair. Depreciating the plant at 20 per cent. per annum and assuming 500 poles built per year, the total cost per pole would be:

Initial cost of pole	$9.85
Forms $19.16 for 50 poles	0.38
Depreciation of plant per pole	0.16
Total cost per pole	$10.39

The quantities used in the construction of one pole are: Cement, 4.5 bags; sand, ⅓ cu. yd.; stone, ⅓ cu. yd.; steel, .625 in.; 118 ft. or 156.7 lbs., and .5 in., 190 ft. or 161.5 lbs.

These poles are intended to be used instead of 7-in., 6-in. and 5-in. wrough iron tubular poles computed for a safe load of 985 lbs. and costing about $35 each, or instead of wooden poles costing $7.50 each.

The weight of these poles complete is 2,550 lbs. and their erection is accomplished, as illustrated, with a steel derrick wagon which was constructed by the company, using the frame of an old road scraper and a wooden boom made from a wooden trolley pole.

Cost of Hollow Concrete Poles. Hexagonal shaped poles, hollow through the center, used by the Oklahoma Gas and Electric Company are described in Engineering Record, Oct. 30, 1909, as follows: A 35-ft. pole measures 7 in. across at the top and 16 in. across at the butt. They are molded in forms made up of 5-ft. sections so that it is possible to cast a pole of practically any length. Steel rods are placed symmetrically about the central axis and at the top and bottom project through holes in steel plates. The rods are bent over at each end and securely fastened. The core, which is wrapped with one thickness of building paper, is suspended within the form by wires at intervals along its length. The concrete used consists of a mixture of 1 part cement, 2 parts sand and 3 parts chats or zinc tailings, which can be obtained in large quantities from the zinc mines of southwestern Missouri. With cement costing $1.50 per barrel, sand at $2 per cubic yard, chats at $2 per cubic yard and labor at $2 per day of eight hours, the cost of manufacturing a 35-ft. pole 7 in. across at the top averages $10. Three men can make three poles per day, according to J. M. Brown, superintendent for the company. A 35-ft. pole molded, hauled to place and set, with steel cross-arms and pins mounted ready for stringing wires, costs $18. It is claimed that concrete poles are more rigid than wooden poles, their maintenance cost is small, and, being hollow, wires can be run inside of them.

Cost of Concrete Electric-Lamp Poles for St. Mary's Falls Canal. L. C. Sabin gives the following costs in Engineering News, March 2, 1911. The poles are 11 ins. square at the base, and 6 ins. at the top, with the corners chamfered by inserting in the corners of the mold triangular strips 1 in. on a side. The reinforcement consists of one .625-in. square, twisted bar, 35 ft. long, in each corner, extending from about a foot above the base to the top, and two similar bars .5-in. square, 25 ft. long, in each side, extending to within 9 ft. of the top, so that the cross-sectional area of the reinforcement for the bottom part of the pole is 3.56 sq. ins., but for the top 9 ft. of the pole it is but 1.56 sq. ins. The bars were tied together at intervals of 4 ft., with two turns of No. 6 soft-steel wire, bent to a square, within which the rods are placed and secured at proper spacing by winding with stove wire. (Fig. 8.)

In the center of each pole is placed a standard black gas pipe, 1.25 ins. diameter, in two lengths of 15 ft., to lead the wires from the cutout box, near the base, to the top crook or goose neck. At the upper end of this pipe is placed a 2 x 1.25-in. reducer to connect with the 2-in. pipe forming the goose neck, and at the bottom it terminates in a 1.25-in. bend leading through the concrete to the

cutout box The top of the pole is finished with a special top casting, inclosing the upper end of the gas pipe, the reducer and the lower end of the goose neck. Fitted above this is a special conical watershed casting so made that an annular space between the latter and the lower part of the goose neck may be calked with lead or asphalt insulating compound. The cast-iron cutout box, of special design, covers the series cutout and the outlets of both ducts. The pole steps are of .625-in. round galvanized iron, 10 ins. long, projecting 5 ins., and are bent near the end in order to clear the central pipe.

The poles were molded in a horizontal position and the forms for the concrete are shown in Fig. 8. In order to support the pole uniformly without an excessive amount of blocking, the foundation timbers were of 12 by 12 in. fir, 36 ft. long, which were on hand. Six of these were planed on one side, and framed, and the remainder of the mold was made in duplicate. This permitted one pole to be made each day, and provided for removing the sides 24 hrs. after being made and leaving the pole on its firm support for about a week. The forms for the sides, secured by cleats bolted to the 12 by 12 in. timber, were so prepared as to be readily removed and placed on another timber. The method of supporting the pole steps shown was a little device that saved much time, and permitted the side pieces of the mold to be removed without disturbing the steps.

The concrete aggregate was of limestone screenings passing a screen having 1-in. square openings. The proportions used were 1.125 bbls. of cement, 7 cu. ft. of river sand and 14 cu. ft. of screenings. This batch made about 15 cu. ft. of concrete, or sufficient for one pole. It was mixed by hand, quite wet, and well puddled about the reinforcement. The top surface, forming one side of the pole, was finished as soon as ready. The following day the sides of the mold were removed and the two sides of the pole finished. After about a week, the pole was carefully tipped over on another 12 by 12 in. timber so that the remaining side could be finished, and when this was completed the pole was moved to storage. For finishing the sides the film of neat cement was removed by rubbing with a flat piece of sandstone and water, leaving a "sand" finish. Later, carborundum blocks were found well adapted to this purpose.

When not governed by some special conditions, the poles are set 31.5 ft. back from the face of the canal wall, in a block of mass concrete 3 ft. square by about 4 ft. deep. The method of setting was as follows: After digging the hole for the base, a flat stone was placed in the bottom, at the desired elevation, to receive the bottom of the pole. The pole was then laid at right angles to the canal wall, with the butt over the hole and the top extending away from the canal. Along the lower side of the pole was secured an 8 by 8 in. timber, in which was cut, transversely, a semi-circular groove to fit over a timber roller about 6 ins. in diameter. This roller rested in two similar grooves, cut in 12 by 12 in. blocks staked to the ground, and formed a hinge about which the pole

could revolve in a vertical plane at right angles to the canal wall. This hinge was so set that when the pole touched the stone at the bottom of the excavation it would be at an angle of about 45 deg. A floating derrick, with 45-ft. boom, lying in the canal opposite the pole, was used to hoist it into position, the pole first turning about the hinge and later about the lower corner resting on the stone. Some poles, set nearer the canal wall than the above, were hoisted into position with the derrick without using the hinge. After the pole was in place and secured by guy lines, the concrete was mixed by hand and filled around it. Where the sides of the excavation stood up well no forms were used below the ground surface, but in case much caving had taken place, a rough mold was used for the lower part of the base. A plank form was used

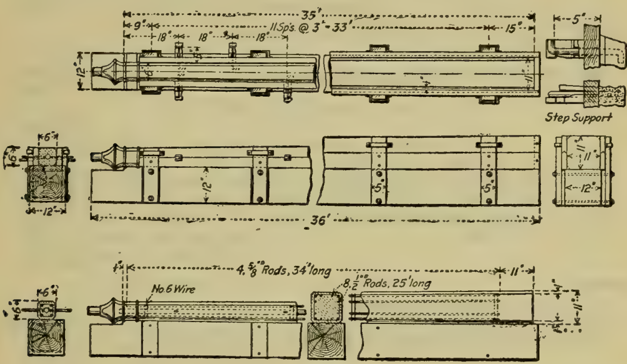


Fig. 9. Forms and reinforcement for reinforced concrete electric-lamp poles, St. Marys Falls Canal, Michigan.

for the upper part above the ground surface, and this part was finished as usual after the removal of the form. After the concrete in the base had set the guys were removed and the pole wired for service. This consisted in laying, in a shallow trench, 2 in. galvanized duct from the manhole of the main conduits opposite the light to the 2 in. bend or crook imbedded in the base, and leading the necessary wires from this manhole to the outlet bell at the extreme end of the goose neck.

The material and labor required in the construction of one pole, and the cost, are given in Table XV. The wages paid for eight hours' work were as follows: Foreman, $3; carpenters, $2.25 to $2.75; cement finisher, $2.25; common labor, $2 per day. The entire cost of forms is included in the cost of 42 poles, although much of the material is good for further use.

For comparison with these reinforced-concrete poles, an estimate may be made of the cost of a wooden pole, with a pipe leading up

the outside, with a goose neck at the top, and set in a concrete base, as follows:

1-12 by 12-in. 36-ft. stick of fir at $30 per M. ft. b.m.	$12.96	
Pipe, steps and top casting	3.37	
4 man-days labor trimming pole at $2.25	9.00	
Cost of pole in yard		$25.33
Transportation of pole to site		3.00
Erection, including concrete base		22.00
Wiring, etc., same as for concrete pole		25.67
Total cost of wooden pole in place and wired		$76.00

TABLE XV. COST OF REINFORCED-CONCRETE ELECTRIC-LAMP POLES FOR ST. MARY'S FALLS CANAL

CONSTRUCTION

(Based on 40 poles.)

Materials — Reinforcement.	
350 lbs. cold twisted steel at 2.7 cts.	$9.45
4 lbs. wire	.10
	$9.55
Pipe, etc., built into the pole.	
26 ft. 1¼-in. steel gas pipe at 4.2 cts.	$1.09
1 2 × 1¼-in. reducer (at top to attach crook)	.10
1 1¼-in. bend (at bottom of pipe in pole)	.32
22 10-in. galv. pile steps at 3 cts.	.66
1 top casting	1.20
	$3.37
Concrete.	
1⅛ bbls. cement at $1.44	$1.62
0.26 cu. yd. sand at 55 cts.	.14
0.52 cu. yd. screenings at $1.10	.57
	$2.33
Forms (for 42 poles).	
Lumber	$75.12
Bolts, pail and iron	10.45
Labor, building	189.67
Total	$275.24
Labor and Transporting Materials.	
Superintendence	$1.42
Hauling material, labor and tug service	2.85
Assembling forms	1.55
Assembling reinforcement	1.53
Concreting, stripping and dressing	4.18
Miscellaneous, blacksmith and contingencies	3.14
Total labor and tug service	$14.67
Total cost of pole in yard	$36.47

TRANSPORTATION

Labor	$0.63
Tug (estimated)	3.00
Total	$3.63

ERECTION

(Based on 15 poles and including concrete base.)

Materials.	
1⅜ bbls. cement at $1.44	$1.99
0.46 cu. yd. sand at 55 cts	.25
0.46 cu. yd. screening at $1.10	.50
1.15 cu. yds. broken stone at $1.10	1.26
Transporting, 3 tons, at 50 cts.	1.50
	$5.50
2-in. bend and coupling	$ .92
Labor.	
Superintendence	$2.81
Excavation and backfill	2.54
Erection with derrick	5.97
Mixing and placing concrete, including forms	4.17
Miscellaneous and contingencies	2.20
	$17.69
Total, base and erection	$24.11

WIRING AND FITTING

(Based on nine poles.)

Materials.	
1 watershed	$0.12
1 2-in. crook or goose neck	1.25
1 outlet bell	0.20
1 cutout box	1.25
1 pothead and cutout	4.40
80 ft. No. 6 rubber covered wire, with weatherproof braid at 16¼ cts.	13.00
Miscellaneous supplies	0.30
Total, material	$20.52
Labor, etc.	
Labor of wiring and fitting	$3.63
Transportation of materials and contingencies	1.52
	$5.15
Total, wiring and fitting	$25.67

SUMMARIZED COSTS

Pole as molded, including materials used	$36.47
Transportation of pole to site	3.63
Erection, including concrete base	24.11
Wire, cutout, and other accessories through base and pole to lamp	20.52
Wiring and fitting up pole	5.15
Total cost in place and wired	$89.88

Tubular Iron Poles. Figs. 10 and 11 give the weight of standard and extra heavy poles for various safe loads, applied as a maximum side strain near the top without causing permanent deflection with the poles set 6 ft. in the ground. The weights are for poles without sleeves. With protecting sleeves the weight is increased from 6 to 10%.

In general the poles are made up of 3 sections of standard or extra heavy tubing as indicated in Fig. 11.

The cost varies from about 2.75 cts. to 3.5 cts per lb.

Unit Costs of Tubular Iron Poles in Place. We have taken the following from the report of the Traction Valuation Commission,

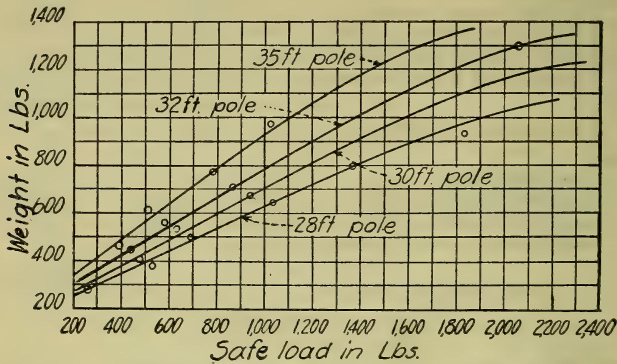


Fig. 10. Standard tubular iron poles (without sleeve).

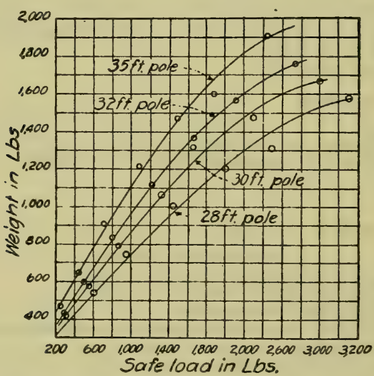


Fig. 11. Extra heavy tubular iron poles (without sleeve).

consisting of Bion J. Arnold, Mortimer E. Cooley and A. B. du Pont, Chicago, 1906:

30 ft. poles, average weight 913 lbs. each, at 2¾ cts.......	$25.10
Labor and concrete, etc., erecting	5.50
Total per pole in place	$30.60

From report of Traction Valuation Commission, consisting of Bion J. Arnold and Geo. Weston, Chicago, 1908:

Length, ft.	Weight, lbs.	Cost pole	Labor and concrete	Total in place
35	1479	$51.76	$9.24	$61.00
35	1220	42.70	8.55	51.25
30	1322	46.27	8.73	55.00
30	1100	38.50	8.25	46.75
30	525	18.37	6.81	25.18
25	450	15.75	6.62	22.37

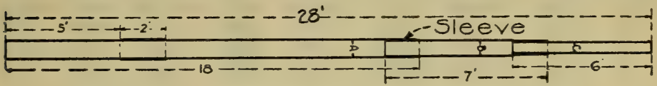


Fig. 12. Construction of a tubular iron pole.

From report of Traction Valuation Commission, consisting of Bion J. Arnold, Geo. Weston and Glenn E. Plumb, Chicago, 1908:

Length, ft.	Weight, lbs.	Cost pole	Labor and concrete	Total in place
30	1000	$30.00	$9	$39.00
28	690	20.20	9	29.20

From appraisal in Detroit in 1909, by F. T. Barcroft:

30 ft. poles, average weight 586 lbs. each, at 2¾ cts.	$16.12
Labor erecting	9.78
Total average in place	$26.90

Cost of Stringing Bare Wire. Table XVI is based upon labor conditions on the Pacific Coast, using different sized gangs in wire stringing in flat country.

The Economic Design of a Distributing System. M. D. Cooper in Electrical World, March 7, 1914, gives the following. The determination of the amount of money which can profitably be invested in a new electrical distribution system or in the reconstruction of an old one is a problem which can often be solved in very definite terms. Its solution is dependent upon the considerations which govern all commercial and engineering problems: "How can the most be got out of a dollar?" or "Will it pay?" These questions can be answered only when it is known how much income can be derived from the investment and how much the charges against the investment and the operating expenses will be.

It is not proposed to treat quantitatively the fixed charges and expenses of a distribution system, for they depend largely upon local conditions. The point it is desired to emphasize is that oftentimes a much greater investment in lines can be justified on an economic and commercial basis than could be justified by the method of analysis heretofore largely used.

Kelvin's Law of Investment and Losses. This analysis is based on Kelvin's laws, which may be stated as follows: "An electric line is built and operated at the least total expense when the fixed expenses on the investment in copper are equal to the cost of the line losses."

TABLE XVI. COST OF STRINGING WIRE

	GANG A				GANG B			
	Copper		Aluminum		Copper		Aluminum	
Size B. & S Gauge or cir. mils.	Miles 1-wire line per day	Cost per mile 1-wr. line	Miles 1-wire line per day	Cost per mile 1-wr. line	Miles 1-wire line per day	Cost per mile 1-wr. line	Miles 1-wire line per day	Cost per mile 1-wr. line
12	2.95	$9.49	2.95	$9.49	5.14	$7.26	5.14	$7.26
10	2.87	9.76	2.87	9.76	4.98	7.49	4.98	7.49
9	2.83	9.89	2.83	9.89	4.90	7.61	4.90	7.61
8	2.77	10.11	2.77	10.11	4.86	7.67	4.86	7.67
7	2.68	10.45	2.68	10.45	4.74	7.87	4.74	7.87
6	2.60	10.77	2.60	10.77	4.61	8.09	4.61	8.09
5	2.50	11.20	2.50	11.20	4.43	8.42	4.43	8.42
4	2.33	12.02	2.33	12.02	4.24	8.80	4.24	8.80
3	2.23	12.56	2.23	12.56	3.98	9.37	3.98	9.37
2	2.04	13.72	2.04	13.72	3.71	10.05	3.71	10.05
1	1.87	14.97	1.87	14.97	3.40	10.97	3.40	10.97
1/0	1.70	16.47	1.70	16.47	3.06	12.19	3.06	12.19
2/0	1.49	18.79	1.49	18.79	2.68	13.92	2.68	13.92
3/0	1.30	21.54	1.33	21.05	2.27	16.43	2.32	16.08
4/0	1.12	25.00	1.14	24.58	1.91	19.53	1.95	19.13
250000	0.965	29.02	1.00	28.00	1.63	22.88	1.69	22.07
275000	0.892	31.39	0.932	30.04	1.49	25.04	1.56	23.91
300000	0.830	33.73	0.880	31.82	1.37	27.23	1.45	25.73
325000	0.773	36.22	0.820	34.15	1.27	29.37	1.35	27.63
350000	0.725	38.62	0.775	36.13	1.18	31.61	1.26	29.61
400000	0.639	43.82	0.676	41.42	1.05	35.53	1.11	33.61
450000	0.571	49.04	0.620	45.16	0.93	40.11	1.10	36.94
500000	0.506	55.33	0.555	50.45	0.84	44.41	0.92	40.55

Gang A consisted of:

1 foreman at $4 per day	$ 4
4 linemen at $3.75 per day	15
4 groundmen at $2.25 per day	9
Total, Gang A	$28

Gang B consisted of:

1 foreman at $5.80 per day	$ 5.80
6 linemen at $3.75 per day	22.50
4 groundmen at $2.25 per day	9.00
Total, Gang B	$37.30

The following example illustrates the truth of this law. Suppose that with an investment in copper of $100,000, the cost of energy consumed in the line amounts to $20,000 per year. If the fixed charges — interest, depreciation, taxes, etc. — are 20% of the investment, these fixed charges amount to $20,000 per year, an amount equal to the cost of the line losses. If the copper were increased twofold the line losses would be cut in half, and conditions would be as follows:

Investment in copper	$200,000
Fixed charges on copper (20%)	40,000
Cost of line losses	10,000
Total annual expenses	$50,000

This amount is seen to be more than in the former case, when the fixed charges were equal to the cost of the line losses. Table XVII shows what conditions would prevail with various changes in the copper investment. It is seen that the most economical operation of the line is secured when the copper investment is such that the fixed costs and the cost of the line losses are equal.

This analysis is based on the primary assumption that a given amount of energy is to be transmitted from one place to another,

TABLE XVII. LOSSES AND CHARGES WITH VARIOUS COPPER INVESTMENT

Investment in copper	Relative investment	Annual fixed charges, 20 per cent.	Relative line losses	Cost of line losses	Total annual expense
$50,000	0.50	$10,000	2.00	$40,000	$50,000
75,000	0.75	15,000	1.33	26,666	41,666
100,000	1.00	20,000	1.00	20,000	40,000
150,000	1.50	30,000	0.66	13,333	43,333
200,000	2.00	40,000	0.50	10,000	50,000

and therefore that any decrease of line losses will decrease the coal consumption correspondingly. Such a method of analysis can be applied only to problems in transmission. When we come to consider distribution, there enter other factors which modify the application of the analysis.

As applied to the distribution system as a whole, Kelvin's law can still be applied to give approximate results, for an increase in the copper investment would decrease the line losses and allow the maintenance of the same average delivered pressure with a reduction in the station voltage. The intangible but positive value of good regulation as an asset in favor of greater line investment makes it impossible, even in this case, to make strict application of Kelvin's law. As applied to a single feeder (without a regulator) or to a limited district, an increase in copper investment will decrease the line losses by some certain amount, but if the same total amount of energy is delivered to the feeder or district, the energy sales must be increased by the amount of the decrease in losses.

Decrease of Wattage with Terminal Pressure. Direct-current motors, incandescent lamps, flatirons and all energy-consuming devices of the resistor class decrease in wattage consumption as the applied voltage is decreased. For this kind of load, therefore, the effect of line loss between the station or the center of distribution and the load is to cause not only a loss of energy in the line but also a decrease in the energy consumed by the load. Moreover, an increase of voltage means a more than proportionately increased energy consumption by the load itself; hence in this case the increase in copper investment results not only in a saving of line loss or a transfer of part of the loss to the energy sold, but also in the sale of additional energy over and above the transfer of line loss.

The question of how much the total increase in energy sale will amount to depends upon the characteristics of the load. If the load is a constant resistance, for which the wattage varies as the square of the voltage, the total increase in energy consumption will be twice as great as the decrease in the line losses. If the wattage varies directly with the voltage, the transfer from line loss will constitute the whole of the increased energy consumption.

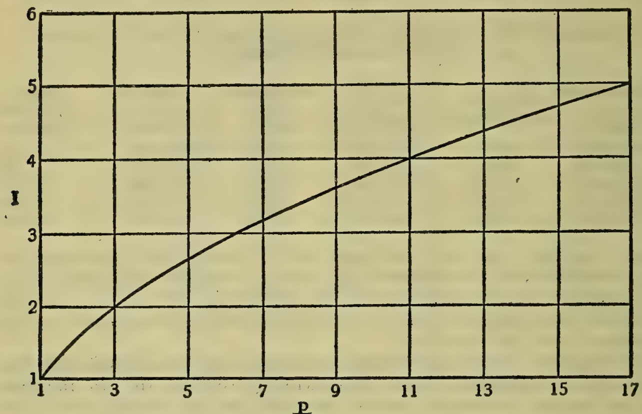


Fig. 13. Curve showing most economical copper investment.

TABLE XVIII. RELATION BETWEEN WATTAGE AND VOLTAGE

Load	Exponent n
Direct-current motor (constant torque load)	0.8 to 1.0
Direct-current motor (generator load)	About 1.0
Alternating-current motor	About 1.0
Flatiron	1.9
Toaster	2.0
Arc lamp	2.0 to 2.2
Incandescent lamp, carbon	1.9
Incandescent lamp, metallized filament	1.8
Incandescent lamp, tungsten filament	1.6

Table XVIII gives data showing the relation between wattage and voltage for various classes of load. The second column, giving empirical exponents in the assumed relation wattage, varies as $(\text{voltage})^n$. This table establishes the fact that about 1.5 is a conservative figure for the average exponent in the assumed relation of wattage to voltage.

In general it can therefore be said that a line reconstruction which decreases the energy loss in the lines by a certain amount in k.w.-hrs. will increase the energy sales by about one and one-half times that amount.

The effect of this reconstruction is, therefore, not only to decrease the losses but to increase the sale of energy. In applying Kelvin's law the decreased loss is taken into account but no consideration is given to the increased energy sale. Since the sale price of energy is often many times the direct or increment cost of generation, it is evident that a most important item has thus been neglected.

TABLE XIX. RELATION BETWEEN COPPER INVESTMENT AND COSTS

	Relative copper investment				
	1.00	1.75	2.00	2.25	2.50
(1) Copper investment.	$100,000	$175,000	$200,000	$225,000	$250,000
(2) Fixed charges....	20,000	35,000	40,000	45,000	50,000
(3) Cost of line losses.*	20,000	11,430	10,000	8,888	8,000
(4) Total expense ...	40,000	46,430	50,000	53,888	58,000
(5) Transfer from losses to energy sales, $20,000 minus (3)	.....	8,570	10,000	11,111	12,000
(6) Extra energy generated and sold, half of (5)........	.....	4,285	5,000	5,555	6,000
(7) Total increase in energy sales (5) plus (6)	.....	12,855	15,000	16,666	18,000
(8) Gross profit on same, two times (7)	.....	25,710	30,000	33,333	36,000
(9) Net expense, (4) minus (8)	40,000	20,720	20,000	20,555	22,000

* The values given neglect the extra line loss due to the increase in line current. This affects the final result less than 1 per cent.

Returning to the previous example, Table XIX is given to determine the most economical copper investment, assuming that the selling price of energy is three times the direct or increment cost of generation.

This table shows that when the sale price of energy is three times the direct or increment cost of generation the most economical copper investment is twice as much as the amount that would be indicated by applying Kelvin's law.

It can be shown that if the ratio of sale price of energy to the direct cost of generation is p, then, considering this fact, the ratio I of the actual economical copper investment to the apparent economical copper investment as derived by Kelvin's law is given by the relation

$$I = \sqrt{\frac{3p - 1}{2}}$$

The accompanying curve shows this relation in a graphical form.

The advisability of investing more money in copper in the reconstruction of old lines and the determination of the amount of copper to use in new lines are problems which require study from several standpoints, one or more of which may govern the final

solution. As has been brought out in this article, ordinary conditions of operation will almost always commercially justify a much greater investment in copper than could be justified on the basis of Kelvin's law.

Cost of Constructing Pole Lines. J. M. Drabelle in a paper on factors determining rural line extensions states that the cost of constructing pole lines and stringing wires for 2,300-volt to 6,600-volt systems is from $325 to $425 per mile.

H. W. Garner states that the style and cost of construction of small lines should to a certain extent depend on the probable amount of revenue obtainable from the localities supplied and advises the use of wooden-pole single phase lines costing from $500 to $1,200 per mile complete for lines radiating from one small locality to other small towns.

Cost of 2,300-Volt Line. Rufus E. Lee gives the cost of constructing a 2,300-volt line on steel tripartite poles set in concrete as $600 per mile on the first 15 miles and $800 per mile on the last 17 miles of a 32 mile line. Long haulage of poles and construction supplies is said to account for the increased cost on the latter part of the work.

Labor Cost of Building a Transmission Line. A power transmission line described in Engineering and Contracting, Feb. 5, 1908, was to be run about 20 miles. For all but 9,500 ft. of this distance poles were up and being used for other purposes. For the distance named an entirely new line had to be built along a public road. The poles and cross arms were delivered at one end of the line by railroad, so the average haul on material was about one mile. The poles were from 30 to 33 ft. long, measuring from 5 to 9 ins. at the top and from 12 to 18 ins. at the butt.

The wages paid for a 10-hr. day on the work were as follows:

Foreman	$3.00
Laborers	1.50
Lineman	2.50
Team 2 horses and driver	4.50

Hauling. The poles were hauled on a two-horse wagon, one man assisting the driver in loading and unloading them. Naturally a large per cent. of the cost of hauling was in taking the poles from the cars and unloading them from the wagon. The poles were of chestnut, fairly light, and 8 to 10 poles could be hauled at a trip. The cost of hauling the poles was:

Team	$22.50
Laborers	7.50
Total	$30.00

Digging Holes. In digging the holes for the poles, one man worked on a hole. He used a digging bar, a shovel with extra long handle and a spoon with same length handle. The holes were dug 5 ft. deep and were 30 ins. in diam. at the top and about 18 ins. at the bottom, making an average diameter of 2 ft. From each

TABLE XX. DETAILED COST OF ELECTRICAL DISTRIBUTION SYSTEMS PER CONSUMER AND PER CAPITA OF POPULATION SERVED (1911)

Location	Pop. of city	No. of cons.	Total cap'y transf.	Transfer. cap. per consumer k.w.	Poles	Wire	Transformers	Meters and services	Complete distrib. system	Cost of distrib. system per cap	Remarks
No. Dak....	4,500	400	....	....	$8.57	$11.25	$6.00	$20.00	$44.82	$4.00	A. C.
So. Dak....	5,200	635	422	.664	6.30	9.81	3.33	9.85	29.29	3.58	A. c.
So. Dak.....	5,400	884	....	....	8.69	10.77	....	18.00	37.46	3.94	D. c.
No. Dak....	5,500	600	....	....	16.00	16.66	9.00	19.46	61.12	6.68	A. c. & d. c.
No. Dak....	6,620	1,176	270	.23	6.75	10.27	4.59	22.19	43.83	7.79	A. c. & 3 wire 220 v. d. c.
So. Dak....	6,800	724	398	.55	6.90	7.20	9.00	12.98	36.08	3.84	A. c.
Iowa	12,000	1,400	718	.51	6.25	8.52	8.45	19.10	36.07	4.94	A. c & 500 v. d. c.
No. Dak....	14,000	450	....	....	50.60	90.00	9.15	26.25	176.60	5.68	A. c. & d. c. part underg'd (bus. underdeveloped.)
No. Dak....	18,000	2,200	722	.328	8.21	13.25	4.63	11.40	37.49	4.58	A. c. & 3 wire d. c. 2 cos.
Missouri ...	19,500	540	386	.715	33.05	36.67	12.06	20.55	102.33	2.84	A. c. competing plant idle pole lines.
Ohio	23,000	1,875	1,372	.73	11.70	21.60	11.70	19.65	64.65	5.27	A. c. & d. c.
Ohio	26,000	3,400	5,900	1.74	16.65	31.70	27.80	19.55	95.70	5.78	A. c.
Illinois	30,000	5,041	1,176	.233	13.27	16.30	3.58	21.92	55.07	9.27	A. c. & 3 wire d. c. 2 cos.
Illinois	43,000	2,250	1,077	.479	12.03	19.22	7.33	24.12	62.70	3.20	A. c. & 500 v. d. c.
Illinois	45,000	2,225	1,540	.692	14.83	21.11	8.54	22.47	62.12	3.31	A. c. & 3 wire d. c. 2 cos.

Average cost of complete distribution system per capita, $4.85.
In above figures no engineering or overhead charges included.

hole was excavated 0.58 cu. yd. The material was a red sandy clay, and the holes were all dry. There were 74 holes dug. The cost was:

Foreman	$17.25
Laborers	55.50
Total	$72.75

The cost per hole was as follows:

Foreman	$0.23
Men	0.75
Total	$0.98

The cost per cu. yd. was as follows:

Foreman	$0.40
Men	1.30
Total	$1.70

It will be noticed that one man dug 2 holes per day. On another job holes 5 ft. in diameter and 5 ft. deep were dug at the rate of two per man-day, at the same rate as these holes were dug. On these larger holes about 6 times as much earth was handled at the same cost, thus showing how much cheaper earth can be handled from a hole large enough to admit of a man working in it. The hole poles had to be dug by the man standing over the hole. Another item that affects the cost is that on the larger diameter holes, two men worked together, while on the pole holes only one man worked on a hole, which meant a slow pace.

Raising Poles. The pole raising was done by hand. A deadman and a jenny were used, these being manipulated by two men. The foreman or a lineman held a metal slide in the hole for the butt of the pole to slide against, keeping it from gouging into the side of the hole. The rest of the crew used pikes to lift the top of the pole, and place it in the hole. The crew consisted of the foreman, one lineman and about 7 men.

The method of operation was as follows: The pole was rolled to the hole by means of bars and cant hooks. The slide meantime was placed in the hole. Then the crew lifted the small end onto the jenny which held it until the deadman was put in place. With the pole resting on the deadman, the pikes were brought into play, and as the pole was lifted the deadman was moved up under the pole until the final lift came that sent the pole into the hole. Then it was turned and lined up, the lineman assisting the foreman in this work, after which the refilling of the hole was done.

A record of this work was kept in detail on a number of poles, from which it was found that the average time consumed in the work was as follows:

Getting ready to set pole, 3 min.; raising pole, 6 min.; lining pole, 2 min.; filling and tamping earth in hole, 1 man shovelling and 3 tamping, 10 min., several men standing by the pikes to steady the pikes; moving to next hole, 4 min.; total time, 25 min.

When everything is working well this average can be maintained, but a little time is occasionally lost due to unforeseen obstacles that prevent this speed. The cost of raising the poles was:

Foreman	$10.50
Laborers	37.50
Lineman	8.75
Total	$56.75

This, for the 74 poles, gives a cost per pole of the following:

Foreman	$0.14
Laborers	0.50
Lineman	0.12
Total	$0.76

Cross Arms. Before raising the poles, and while the laborers were digging the holes, the linemen were at work dapping the poles to receive the cross arms. The cross arms used were 8-pin arms, two being placed on each pole. At all times in the line, double cross arms were used, that is, a cross arm was put on each side of the poles. This was the case for nine poles. For future needs the poles were dapped in 3 places. This made 240 days necessary. The poles, as stated, were chestnut. The cost of dapping the poles was $22.62, making a cost per dap of 9.8 cts.

One lineman placed the cross arms, the team hauling them along as needed, and the driver acting as the lineman's "ground hog." The sketch shows how these arms were placed, and braced with two pieces of galvanized iron. In all, 166 cross arms were used. The cost of this work was:

Hauling with team	$21.37
Lineman	6.25
Total	$27.62

The high cost of this was due to the fact that the team was charged to this work for the entire time of placing the cross arms, as it waited at each pole while the arms were being put in place. The cost per cross arm was 17 cts.

One lineman and a helper placed the insulators. The cost of this was:

Lineman	$3.75
Helper	2.25
Total	$6.00

Only six insulators were put on a cross arm, thus making 12 to a pole, except at the turns, as the line was to carry 12 wires. In all 996 insulators were used, hence the cost per unit was 0.6 ct.

Guy Poles. In building lines with a number of wires on them, it is necessary to guy all poles where there are turns in the line, and on long straight lines some of the poles must also be guyed.

The sketch shows the method used in guying this line, and is one frequently used. The guy pole holes were dug of about the same dimensions as the holes for the line poles. The cost was:

Foreman	$1.50
Laborers	6.75
Total	$8.25

The cost per pole was:

Foreman	$0.17
Laborers	0.75
Total	$0.92

The raising of the poles cost:

Foreman	$3.00
Laborers	9.00
Total	$12.00

This makes a cost per hole of $1.33. This is large, owing to the fact that the men lost considerable time moving from pole to pole and carrying their tools, also to the fact that each pole had to be cut and trimmed, as these guy poles were made from rejected line poles.

The method of placing the guy wires to the poles was as follows: The wire was fastened to each of the two poles, and then brought to the tightening block as shown in the sketch. With blocks and tackle fastened to the two poles, the poles were brought to a snug bearing and the wires were made fast around the tightening block, shown in the sketch. The wires go around the block in grooves made for the purpose at right angles to each other. While the linemen and their helpers are doing this work, the laborers are digging the anchor hole and placing the anchor rod. To this is fastened a turn buckle, and a wire is run from the guy pole to the turn buckle. The blocks and tackle are then fastened to a handy tree or stump, or if necessary to the anchor rod and the guy pole is pulled back, tightening the guy wire between the two poles, while the turn buckle is screwed up, thus making all the guy wires taut. At times, instead of making an anchor as shown, the anchor wire can be fastened to a convenient tree. Both kinds of anchors were used in this case. The cost of this work was:

Foreman	$1.50
Linemen	3.75
Laborers	3.75
Total	$9.00

This made a cost of $1.00 per pole, making a total cost per guy pole of $3.25.

About one-half of this line ran through the edge of woods or by shade trees. A few trees had to be cut down and a number

trimmed; some tall bushes were also cut down. The foreman looked after this work part of one day when all his force was at work upon it, but for the most part linemen were in charge of several laborers doing this work. The cost of it was as follows:

Foreman	$ 2.25
Lineman	18.12
Men	13.13
Total	$33.50

Stringing the Wires. As previously stated, 12 wires were strung on the poles. The wires were light weight. The team hauled the wire, and one horse was used in helping to string it, the other horse standing idle. In line work, a team is nearly always necessary, yet there are times that it may stand idle for hours, thus increasing the cost of that item to which it is charged. When there is nothing else for the wagon to do it is used to carry the tools along the line as the men work. In stringing the wire the horse pulled a rope fastened to two strands of wire at one time, thus running out two wires, and making six trips of the horse to string out the 12 wires. For this work 3 linemen were used, but in fastening the wires to the insulators only 2 linemen were used, and the wires were pulled tight by the helpers with blocks and tackle. The cost was:

Foreman	$ 18.00
Linemen	37.50
Laborers	27.00
Team	36.00
Total	$118.50

In all 21.6 miles of wire were strung and this made a cost of $5.50 per mile of wire.

Changing Poles. At the ends of the line, where connections were made with the old line of poles, some poles had to be changed to make them suitable for the new service. There were 3 of these at one end and 1 at the other. The work consisted in taking down the old poles and putting in their place poles from 40 to 45 ft. long. Cross arms had to be put on the new poles, and the wires changed over to the new poles. It took a half day for the crew to do each pole, thus spending 2 days on the 4 poles. The cost of this was:

Foreman	$ 6.00
Lineman	2.50
Laborers	39.00
Team	9.00
Total	$56.50

This gave a cost per pole of $14.12. In line work the foreman is always a lineman, and in doing odd jobs this frequently keeps the cost down, as he will often do work that a lineman is called upon to do. As the lineman is the higher priced man he should be allowed to do only such work as the helper is not able to do.

Total Cost. The total cost of the entire work was as follows:

Hauling	$ 30.00
Digging holes	72.75
Raising poles	56.75
Dapping cross arms	22.62
Placing cross arms and insulators	33.62
Guy poles	29.25
Trimming trees and bushes	33.50
Stringing and fastening wires	118.50
Changing old poles	56.50
Total	$453.49

There being 1.6 miles of line built, the cost per mile for each item was:

Hauling	$ 18.75
Digging holes	45.47
Raising poles	35.47
Dapping cross arms	14.14
Placing cross arms and insulators	21.01
Guy poles	18.28
Trimming trees and bushes	20.94
Stringing and fastening wires	74.06
Changing old poles	35.31
Total	$283.43

For the 74 new poles erected this makes a cost per pole for the completed line of $6.13.

Reducing the Cost of Line Construction. Comparative tests conducted in St. Louis, Mo., and described in Electrical World, May 30, 1914, seem to show that the cost of overhead distribution line construction may be reduced to nearly ⅓ its former value by the use of a combination primary-secondary distribution rack. In addition to the economic record shown, the distribution rack has the further advantage of presenting a neat and finished appearance on the poles. For this reason the alley between Westmoreland and Portland Places, exclusive residence districts in St. Louis, was selected as the site for the experimental line. The site of the experimental standard line was in another part of the city. In all fairness it should be said that the standard line was built on a street free from trees and obstructions, under more favorable conditions than was the bracket line, where there were alley fences to be climbed and carefully kept lawns had to be avoided. Equal numbers of secondary services were installed on each line, making the necessary labor as nearly identical as possible.

As will be noted from data in the accompanying tables, the cost of building the standard primary-secondary distribution system, inclusive of material, labor, painting, extra haulage and overhead charges, was $116.13. For the competing line using distribution-rack construction the cost was $45.24, no charge being included for extra haulage, as the crew were able to carry all material in the gang automobile. These figures show that the standard construction really cost two and one-half times as much as the distribution-

rack construction, although the former was built under the more favorable conditions. Data in the accompanying tables show what material was used and give total costs.

The distribution racks, which will be marketed by W. N. Matthews & Brother, of St. Louis, consist of a line, while the secondary pins are cast integral with the vertical channel. Two through-bolt suspension has been used in St. Louis, but a single stud bolt with a lag screw in the lower hole may be utilized satisfactorily.

Standard primary-arm construction

Material:	No. of pieces
Primary arms	15
24-in. cross-arm braces	30
0.625-in. by 12-in. machine bolts	15
0.625-in. by 5-in. lag screws	15
Pins	30
Clamps	15
Square washers	30
Labor:	**Hours**
Seven piece, one and one-half hours each	10.5
Automobile	1.5

Standard secondary-arm construction

Material:	No. of pieces
Secondary arms	15
24-in. bracer	30
0.625-in. by 14-in. machine bolts	15
0.625-in. by 5-in. lag screws	15
Pins	60
Through-point spreaders	30
Malleable pole-back brackets	15
2-in. by 0.25-in. lag screws	60
Labor:	**Hours**
Seven piece, one and three-quarter hours each	12.25
Automobile	1.75
Extra team to haul arms	21.00
Driver	21.00

Material and labor to apply on cost of lead and oil paint

Material:	Amount
White lead in oil, 1 lb.	10.0
Boiled linseed oil, gal	1.5
Turpentine, gal.	0.5
Japan drier, pt.	0.25
Dry red mineral, lb.	4.33
Labor:	**Hours**
One man painting	2.5
Two men fitting up	5.0
Total cost	$116.13

Combination distribution-rack construction

Material:	Number of pieces
Brackets complete	15
0.625-in. by 12-in. machine bolts	30
Square washers	30
0.375-in. by 2-in. machine bolts	15
Western Union pins	30

Labor:	Hours
Three men, two hours each	6
Automobile	2
Total cost	$45.24

Itemized Cost of Two Telephone Lines. Data for telephone construction are given in Engineering-Contracting, July 24, 1907, for two short lines, one 10 miles long and the other 14 miles long. The cost of the 10 mile line was as follows per mile:

Labor:	
1.7 days foreman at $4.00	$ 6.80
1.7 days sub-foreman at $3.00	5.10
4.0 days climbers at $2.50	10.00
10.5 days groundmen at $2.25	23.63
17.9 days total at $3.10	$55.53
Materials:	
28 poles at $1.50	$ 42.00
28 cross arms at $0.15	4.20
28 steel pins at 0.04	1.12
28 glass insulators at 0.04	1.12
56 lag screws and washers at 0.015	0.84
305 lbs. No. 9 galv. wire at 0.042	12.81
Total materials	$ 62.09
Total labor and materials	$117.62

More than 90% of the poles were 25 ft. long. The rest were 30 to 40 ft. in length.

The cost of the 14 mile line was as follows per mile:

Labor:	
2.2 days foreman at $3.50	$ 7.70
2.2 days sub-foreman at $3.00	6.60
5.3 days climber at $2.75	14.58
11.4 days groundman at $2.25	25.64
21.5 days total at $2.54	$54.52
Materials:	
32 poles at $1.50	$48.00
32 brackets at 0.015	0.48
380 lbs. No. 8 galv. wire, 0.042	15.96
10 lbs. No. 9 galv. wire, 0.042	0.42
1½ lbs. fence staples, 0.025	0.04
32 insulators, 0.04	1.28
Total materials	$66.18
Total labor and materials	$120.70
2 telephones at $12.50	25.00
200 ft. office wire	1.40

Considering the low cost of telephone lines of this character, it is surprising that they are not more frequently built for use on construction work. For temporary purposes, a much cheaper kind of poles could be used. For example, a very substantial pole could be made by nailing together two 1 x 4-in. boards, so as to form a post having a T-shaped cross-section. Such a pole would contain only two-thirds of a foot, board measure (⅔ ft. b. m.) per lineal

foot of pole. At $24 per M for the boards, a pole 20 ft. long would cost 32 cts.

Hence the poles would cost less than $10 per mile of line. The No. 9 wire would ordinarily cost less than $13 per mile, and $3 more would cover the cost of the remaining line materials, making a total cost of $26 per mile for materials. We have no data as to the labor of erecting such a line, but it would certainly be less than $15 per mile; and in soil where post hole diggers could be used, the cost would be considerably less. In fact, a telephone line built for $35 a mile might easily be obtained under fairly favorable conditions. Moreover it could be taken down and used many times on subsequent construction.

Itemized Cost of a 28-Mile Telegraph Line. Data given in Engineering and Contracting, July 10, 1907, relate to a telegraph line 28 miles long, built in British Columbia. There were 32 poles to the mile, strung with a single No. 8 B. B. galvanized iron wire. The cost of the poles was very much less than it would be in most localities, but, since quotations on poles are readily secured, proper substitutions can be made in the following tabulated values for any particular case.

Size and Weight of Telegraph Wire. Until recently the size of wire commonly used for lines of medium length, up to 400 miles, was No. 9, weighing 305 lbs. per mile, but No. 8 is now used more frequently. There are two grades commonly used: the E. B. B., or "extra best best"; and the B. B., or "best best." A third grade S, or "steel," is also used for short circuits. The following are the weights of galvanized wire:

Size No.	Lbs. per mile	Lb. per ft.	Ft. per lb.
6	570	0.108	9.2
7	450	0.085	11.7
8	380	0.072	14.0
9	305	0.058	17.4
10	250	0.047	21.2

The itemized cost of this 28 mile line was as follows:

Labor:	
1.0 day, foreman at $3.50	$ 3.50
1.0 day, sub-foreman at $3.00	3.00
2.7 days, climber at $2.50	6.75
2.5 days, framer at $2.25	5.62
0.7 day, blacksmith at $2.25	1.58
4.6 days, groundman at $2.00	9.20
12.5 days total at $2.40	$29.65
Materials:	
32 poles (25-ft.) at $1.25	$40.00
32 wooden brackets at 1¼ cts.	0.40
32 glass insulators at 0.4 cts.	1.28
5 lbs. nails at 2½ cts.	0.12
½ lb. staples at 0.3 cts.	0.02
380 lbs. No. 8 BB galv. wire at 5 cts.	19.00
2 lbs. tie wire at 3 cts.	0.06
Total materials	$60.88
Total labor and materials	$90.53

The labor includes the cost of digging holes, erecting poles, stringing the wire, etc. The poles were distributed by train, and the price of $1.25 per pole does not include the train service.

Cost of Telephone Lines. The costs in Table XXI are estimates based on average conditions in the Middle West.

TABLE XXI. COST OF BARE COPPER AERIAL LINES

	50 wire line 40 ft. poles	100 wire line 45 ft. poles	200 wire line 60 ft. poles
Poles, cedar, 35 per mile....	$208	$290	$590
Poles, setting	87	105	165
Cross-arms, 10 pins	77	154	306
Cross-arms, attaching to poles	26	53	105
Braces and screws.........	13	26	53
Pins	14	26	36
Pins, attaching to arms....	2	4	8
Insulators	17	35	70
Insulators, attaching to pins	8	18	35
No. 14 B. & S. G. hard drawn cop. wire.........	488	975	1,950
Labor, stringing wire.......	250	500	1,000
Total	$1,190	$2,186	$4,318

Cost of Telephone Toll Pole Lines. The average costs for New England States given below are from Data, Feb., 1912, and are

25 FT. POLES, HEAVY CONSTRUCTION

	Average cost per mile
Poles	$125
Guying	7
Cross arms	32
One circuit No. 12 wire	68
Sundries	20
Teaming	20
Labor cross arming	7
Labor poles	105
Labor wire	7
Labor trimming trees	15
Sundry	35
Right of way	50
Average for New England States	$491

Cost of Rural-Service Line. The following is taken from Electrical World, Jan. 16, 1915. Lines of the Noblesville, Ind., Heat, Light & Power Company constructed along country roads to supply the farmers of Hamilton County with electric service are built of 25-ft. poles spaced 200 ft. apart. Following the company's standard practice, using No. 8 bare hard-drawn copper wire and 30-in. telephone cross-arms, the average cost of a mile of line is as shown in Table XXII.

This table of expense includes nothing for supervision, use of tools, insurance or interest, and it is estimated that the actual cost, including everything, is about $300 a mile. The company therefore starts with an initial investment of $100 a mile, since the

farmer customers deposit $200 a mile, and the company's investment is later increased to $300 a mile when it acquires the line.

Assuming that 60% of the gross revenue from this line is used in operating expenses, then 40% is left for interest, depreciation and profit. If interest is assumed at 7% and depreciation at 5%,

TABLE XXII. COST OF A MILE OF RURAL-SERVICE LINE

	Unit price	Item cost
27 poles (25 ft. high with 5-in. top)	$1.15	$31.05
10,560 ft. No. 8 copper wire	0.16	126.40
27 telephone cross-arms	0.13	3.51
27 through bolts	0.05	1.35
54 locust pins	0.013	0.70
54 insulators (porcelain)	0.03	1.62
54 square galvanized washers	0.009	0.50
Guy anchors (average)	....	5.00
Labor and hauling	....	72.00
Total field expense for material and labor	....	$242.23

then 12% of $300, or $36, will need to be charged against each mile of line. Table XXIII, worked out on this basis, shows how much revenue must be received from each customer before his account is profitable.

TABLE XXIII. FINANCIAL DATA ON RURAL-SERVICE LINE

Average monthly bill per customer	Annual gross revenue per mile	Annual net revenue per mile	Annual interest	Annual surplus
$1.00	$48	$19.20	$36	—$16.80
1.50	72	28.80	36	— 7.20
2.00	96	38.40	36	+ 2.40
2.50	120	48.00	36	+ 12.00
3.00	144	57.00	36	21.60
4.00	192	76.00	36	40.80
5.00	240	96.00	36	60.00

From these data it will be seen that until the customer's bill averages nearly $3 a month rural lines are not a paying experiment under these conditions as the interest and depreciation charge includes nothing for the generating station. After the customer has passed the $3 a month average bill, however, he becomes a profitable patron. During the development period the deficit shown is somewhat offset because of the interest charge being lower as the customer has had only a part of his advance payment refunded.

Cost of Steel Tower Lines. T. A. Worcester in a paper before the A. I. E. E., May 17, 1912, says: The size of conductor depends on electrical considerations, except where the length of span is the governing feature.

The length of span, except in river or gorge crossings, is dependent upon the designer and must be chosen so as to give the

line the least cost. As the span increases, the number of towers and insulators per mile decrease, but on the other hand the height of the towers must be increased to care for the greater sag and at the same time they must be made proportionately stronger and heavier to care for the greater loads per span. The effect of these changes on the cost of a line is shown by the curve, Fig. 14. The length of a span affects the loads in the vertical direction and in the horizontal direction across the line and not that parallel to the line, since the latter is governed by the size of the conductor, it being necessary to adjust the sag so as not to exceed the safe stress for the wires.

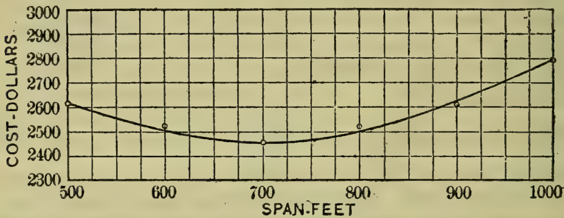


Fig. 14. Cost per mile of towers and insulators erected.

For every size of conductor there is a practical limit of the length of span beyond which the sags and height of tower becomes excessive and there is danger of the wires swinging together. For the smaller sizes of conductor this limit is quite low — 300 ft. for No. 4 cable — and in many cases it will be found more economical to increase the size of conductor so as to permit using a greater span as illustrated in Table XXIV.

TABLE XXIV. RELATION BETWEEN SPAN AND WIRE SIZE

	Span, ft.	Sag, ft.	No. of towers per mile	Cost of towers and insulators per mile erected	Cost of wire and freight per mile	Total per mile
Case I No. 4 B. & S.	300	10.5	17.6	$3,080	$322	$3,402
Case II No. 2 B. & S.	360	10.5	14.7	$2,570	$514	$3,084
Saving per mile						$318

These figures are based on the assumption that the same towers and sags would be used in both cases, giving the same clearance to ground. The sag in Case I is the minimum sag at which wires may be strung on the basis of 0 deg. Fahr., 8 lb. wind, and .5 in. sleet and with these same conditions and sag the span for No. 2 wire is calculated and found to be 360 ft. With this tower spacing

TABLE XXV. DATA ON TYPICAL STEEL TOWERS

Use (a)	Conductors (b)		Number and diam. of ground wires, ins.	Kilowatts between wires	Pin or suspension insulators	Height, ft.		Base, ft.		Weight, lbs.
	Number	Size, cir. mils. or B. & S.				Lowest cross arm	Over-all	Across line	Along line	
L (2)	6	300,000	1–½	110	S	55	79	20	20	6,800
A	6	300,000	1–½	110	S	50	75	24	24	10,500
L (3)	3	683,000 (c)	1–½	150	S	43	47	18	20	4,335
A	3	683,000 (c)	1–½	150	S	37	41	24	24	6,985
L (4)	3	0000	1–⅜	50	P	42	53	95	(d)	2,150 (e)
A	3	0000	1–⅜	50	P	42	53	9	9	3,750
L	3	0	2–⅜	102	S	43	45	14	13	1,800
L	6	000	1–⅜	32	S	51	76	17	17	4,560 (f)
L	6	000	1–⅜	100	S	51	77	17	17	....

(a) L = straight line or suspension tower, A = anchor or angle tower; numbers in brackets refer to accompanying cuts. (b) All conductors stranded. (c) 605,000 cir. mils. of aluminum with a 78,000 cir. mil. steel core. (d) Flexible tower. (e) Including foundation. (f) Average for 197 towers, including anchor towers and hardware.

and No. 2 cable the cost of the line is $318 less than with No. 4 cable and 300 ft. span. It is allowable to assume that the same towers can be used in the second case as in the first since the lightest tower which it is practicable to build would be sufficiently strong for the second case. However, it would be possible to put $20 more into the cost of each tower and still have the cost of the second line a trifle less than that of the first and the gain would accrue from the electrical advantages of the larger size of conductor.

A span of 360 ft. is not necessarily the most economical span for the No. 2 conductor. Further calculation indicates that a 500-ft. span could be used with only a very slight increase in the cost of the towers. This limit cannot be extended beyond 500-ft. even though the line with greater spans would have a less cost. Here again the limit depends on mechanical considerations rather than on costs and is governed by the danger of lashing together of the wires in gusty winds.

Tower Line Cost in Calif. In Chap. I, last part, will be found a detail estimate of the cost of a high voltage tower line, made by H. P. Gillette, based on actual costs.

Ratio of Labor to Material Costs in Steel-Tower Transmission-Line Construction. A. B. Cudebec in Electrical World, July 17, 1915, states that the cost of a heavy tower line may vary from $4,000 to $12,000 per mile of which the materials of construction alone aggregate between 70 and 80%.

Towers for Transmission Lines. Data on dimensions and weights for a number of towers are given in Table XXV. Galvanized towers cost from 2.5 to 4 cts. per lb., f. o. b. factory. Galvanizing costs from 0.5 to 1 ct. per lb., this cost being included in the figures given.

TABLE XXVI. DATA ON TYPICAL TOWER FOUNDATIONS

(Used in connection with the first four towers listed in Table XXV.)

Type	Height, ins., (over-all)	Base, ins.	Lb. of steel	Cu. yd. of concrete
Reinf. conc.	78	60 by 60	500	4.4
Reinf. conc.	96	96 by 96	1,584	14.4
Steel	90	44 by 45	1,285	...
Steel	88	52 by 52	1,865	...

There are 4 foundation blocks per tower designed to project 6 ins. above the ground surface.

Cost per Mile of Pole Lines, for 3-Phase 2,300 to 6,000 Volts. The data in Table XXVII, from six north-central and south-western states, 1909, are from Data. It will be noted that certain items under minimum costs are higher than the average and others under maximum are less than average. These are not errors, but are due to local conditions of each installation. "Installation of Minimum Cost" gives itemized costs of that one of the six installations referred to, the total cost of which was the least; "Maximum" that

one, the total cost of which was greatest; "Average," average cost of equipment for all six installations.

TABLE XXVII. COST OF POLE LINES PER MILE

	Installation of minimum cost	Installation of maximum cost	Average
50 30-ft. poles	$171	$200	$219
50 sets pole hardware	8	16	10
50 2-pin cross arms	17	11	14
150 insulators	7	11	9
Labor setting	55	200	109
Labor stringing wire	30	40	35
Incidentals	10	50	30
	$298	$528	$426

Above figures are exclusive of painting, copper, engineering and general expense.

Comparative Cost of Transmission Lines. C. D. Gray in Engineering News, July 20, 1911, gives the cost per mile of several different types of construction for a three phase, 60,000-volt line, 60 cycle circuit, with No. 1 copper wire and suspension insulators, using four 10-inch discs, together with a suitable grounded conductor carried above the circuit. These figures do not include the cost of right of way, surveys, engineering or contractors' fees.

3-phase overhead, 2300 volts at sending end.

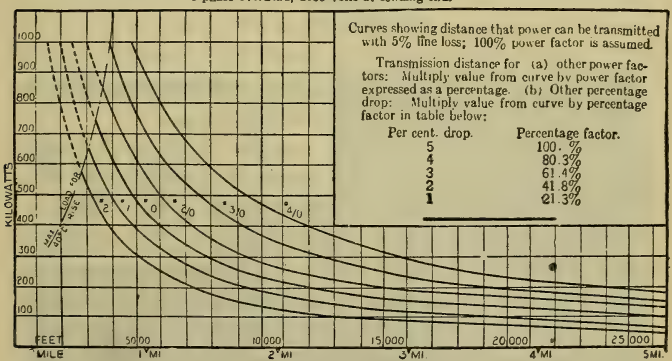


Fig. 15.

The estimated costs are based on the use of 40 ft. 8 in. top chestnut poles, spaced 175 ft. apart, the grounded wire consisting of No. 8 copper clad wire with the main wires supported on steel cross arms and the grounded wire on the top of the pole. The single circuit steel towers have bases about 14 ft. square and the lower

wires 50 ft. from the ground, spaced 500 ft. apart with No. 4 copper clad grounded wire. The double circuit steel towers have the same characteristics as the single circuit.

	Cost per mile
One single circuit wood pole line	$2,550
Two single circuit wood pole lines	5,100
One single circuit steel tower line	2,950
Two single circuit steel tower lines............	5,900
One double circuit steel tower line............	4,600
One double circuit (with one circuit installed)..	3,700

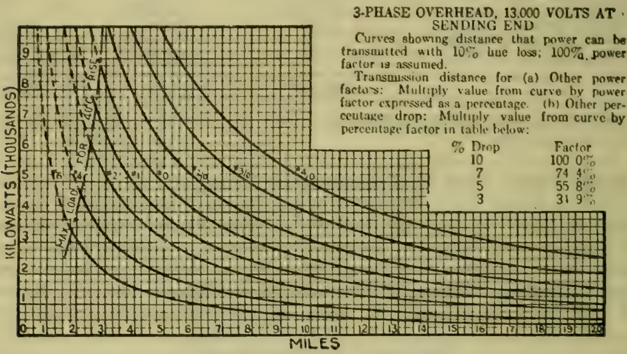


Fig. 16.

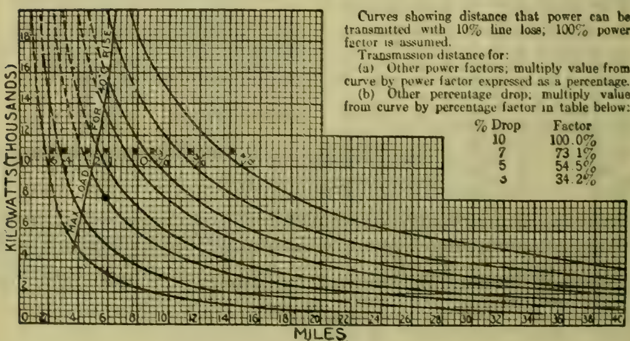


Fig. 17.

Cost of 3-Phase, Single Circuit, High Tension Transmission Lines. Table XXVIII is from Burch's Electric Traction for Railway Trains.

TABLE XXVIII. COST PER MILE TRANSMISSION LINE

Type of construction	Wooden poles		Steel towers
Voltage	13,000	60,000	60,000
Support, 50 poles or 12 towers..	$350	$650	$1,800
Cross arm	100	380	Included above
Telephone line material........	50	50	75
Ground wire material	35	40	100
Insulator pins	35	130	0
Insulators	30	550	155
Three No. 0 wires, erected......	1,000	1,000	1,000
Installation of wires, guys and insulators	200	200	270
Total	$2,000	$3,000	$3,400

Towers for a 6-wire transmission line cost about $2,400.

Estimate omits cost of right-of-way, 15% for contractor's profits, 5% for engineering and 5% for contingencies. Change for actual size of wire to be used.

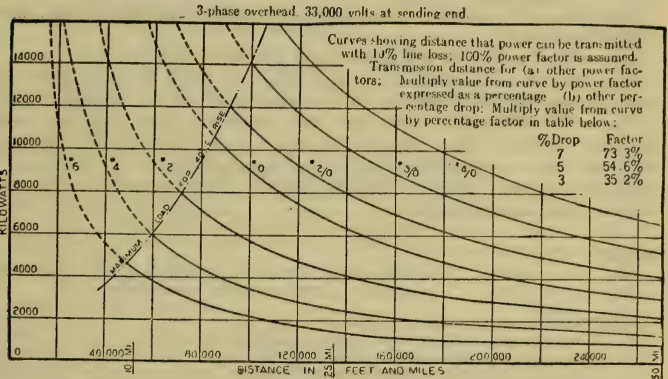


Fig. 18.

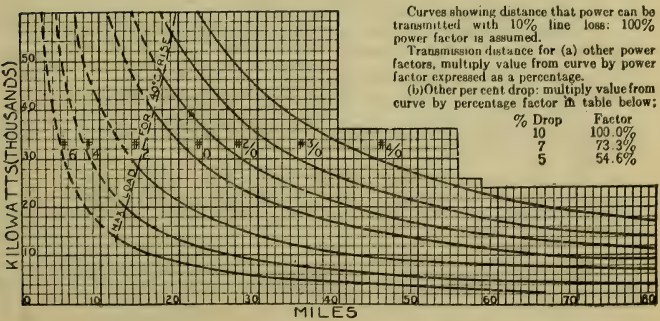


Fig. 19.

Steel Towers vs. Wooden Poles for Electric Lines. G. Nagele gives the following in Lefax: The time is drawing near, when wooden poles will be very expensive. A curve recently published by the United States Government showing the amount of lumber used in the last ten years has no depression showing a temporary decrease of consumption and every year denotes a marked increase in consumption.

Semi-flexible steel structures have many advantages over the wooden pole, and will soon become a standard construction for transmission lines. Some of the advantages of semi-flexible steel poles are:

Long life;

Ability to stand heavy strains;

Will not snap off, but bend to meet the different strains;

Best in swampy grounds;

Less poles to the mile, which means a great reduction in the cost of right-of-way;

Offers protection to the public and property owners.

Herewith is a comparison of the cost per mile of both types of construction of two lines recently constructed in the Middle West.

Cost of Transmission Line per Mile, Wooden Poles. 33,000 volts working pressure, No. 2 B. & S. copper wire; 120-ft. pole spacing, one pole line; 44 poles per mile; pin type insulators; "Bo-Arrow" cross-arms; 35-ft. poles, 7-in. top diam.; .375-in. ground wire (for standard galvanized wire).

Material, labor, etc.

44	Poles, 35-ft., 7-in. top diam. at $8 f.o.b. Ohio	$ 352.00
44	Cross-arms "Bo-Arrow" galvanized complete at $3.79	166.76
44	Telephone brackets at 10 cts.	4.40
	Bog shoes at 15 cts. per pole, average	6.60
	Guying material at 50 cts. per pole	22.00
	Pole steps and hardware at 75 cts.	33.00
	Framing and trimming of poles at 50 cts.	22.00
	Creosoting of poles at 20 cts.	8.80
	Cartage at 70 cts. per pole	30.80
	Hauling (railway) at $1.20 per pole	52.80
	Digging of holes at $1.20 per pole	52.80
	Setting of poles at $1.80 per pole	79.20
3	Miles hard drawn copper strand No. 2 B. & S. at $181.20 per mile	543.60
1	Mile ⅜-in. Siemans-Martin steel strand wire	54.00
2	Miles Tel. wire No. 10 B. & S. copper clad 30% at $25.00 per mile	50.00
44	Ground wire connections at 35 cts. per pole	15.40
132	Porcelain pettycoat insulators at 50 cts.	66.00
	Tie wire	4.50
88	Telephone insulators at 2 cts.	1.76
	Stringing 3 miles No. 2 B. & S. strand at $15	45.00
	Stringing 2 miles No. 10 copper clad wire at $10	20.00
	Stringing ground wire	18.00
	Soldering materials	5.00
	Miscellaneous material	10.00
	Damage, expense to property of owners	5.00
	Clearing of branches and trees	4.50
	Tools	3.00
	Camp expenses	18.00

Materials deposited along the lines for repairs	$ 19.20
Wasted materials	18.00
Contingencies and incidentals, 7%	121.25
Supervision and inspection, 5%	92.67
Total construction cost per mile with wooden poles exclusive of right of way	$1946.04
Right of way at $8 per pole	352.00
Total cost including right of way	$2298.04

Cost of transmission line per mile, semi-flexible steel structures; 33000 volts working pressure, No. 2 B. & S. copper wire; 400-ft. pole spacing, one pole line; 13 poles per mile; 3-disc suspension type insulators; 7/16-in. ground wire (standard galvanized wire).

Material, Labor, etc.

13	Towers (steel frames) 43-ft. high with cross arms, telephone clips and pole steps, complete, f.o.b. central Ohio at $53.00 per tower	$ 689.00
	Cartage at 80 cts. per frame	10.40
	Hauling (railway) at $1.25 per frame	16.25
	Digging of holes at $1.50 per frame	19.50
	Erecting of frames at $2.00	26.00
	Concrete foundations for curve frames and frames in swampy ground	40.00
	Guying of poles	30.00
	Crushed stone for regular foundations	6.00
3	Miles No. 2 B. & S. copper wire at $181.20	543.60
2	Miles No. 10 B. & S. copper clad at $25.00	50.00
1	Mile 7/16-in. S.-M. steel strand wire	75.00
39	Suspension insulators, porcelain 3-disc unit sets including suspension hooks and wire clamps at $3.50	136.50
26	Telephone insulators and pins at 20 cts.	5.20
	Stringing 3 miles No. 2 B. & S. at $18	54.00
	Stringing 2 miles No. 10 B. & S. at $12	24.00
	Stringing ground wire	20.00
	Miscellaneous material	10.00
	Painting of structures at $1.60 each	20.80
	Soldering material	5.00
	Clearing and trimming of trees	4.50
	Damage, expense to property owners	20.00
	Camp expenses	16.00
	Wasted materials	5.00
	Contingencies and incidentals, 6%	109.61
	Supervision and inspection, 5%	96.82
	Total construction cost per mile with steel towers exclusive of right of way	$2033.18
	Right of way at $15 per frame	195.00
	Total cost including right of way	$2228.18

Cost of Labor and Materials of 6,600 Volt Transmission Line 4.6 Miles Long.*

Item	Material	Labor
Poles, crossarms, pins, etc.		
196 poles	$1,673	....
202 cross arms	125	....
202 sets hardware	53	....
1,030 pins (locust paraffined)	43	....
Labor distributing	....	$140
Labor digging holes	....	293

* These data are for construction done during 1913.

Item	Material	Labor
Labor setting and tamping	....	$293
Labor gaining and roofing	....	72
Labor erecting crossarms	....	62
Guying and bracing 4.6 miles	$275	27
Engineering 4.6 miles	....	92
Wire, labor, etc.		
27,075 lbs. #6 ins. two-braid wire	4,642	....
1,850 insulators	186	....
Solder, tape, etc.	14	....
4 lightning arresters	22	....
Miscellaneous	64	....
Labor stringing	....	718
Labor tieing in	....	55
Total	$7,097	$1,753

The total cost for labor and material but not including overheads was $8850, or $1924 per mile.

Cost of Material for 6,600-Volt Line Construction. Electrical World, May 17, 1913, gives the following data bearing upon the cost of line-construction material taken from a tabulation of expenses prepared by the Harvard, Mass., Gas & Electric Company in connection with the erection last year of 6 miles of 6,600-volt line and 12 miles of 2,300-volt distributing system, carrying about 75 miles of copper wire on 628 chestnut poles of from 30-ft. to 45-ft. length. The total cost of material for the work was $13,128.03, and of labor $5,925.69. Including the use of a motor truck for 3713.4 miles at a charge of 20 cents per mile and the time and expenses of engineers making plans and surveys and obtaining public and private rights-of-way, the total cost of the work, with a 15 per cent. commission to the interests in charge of the construction, was $23,542.48.

The detailed items given herewith were selected as of practical value to small companies facing the need of making estimates of line-construction costs elsewhere. The 6,600-volt line was built for the double purpose of enabling the central stations of the Massachusetts lighting companies at Ayer, Leominster and Clinton to interchange energy and to supply local service in Harvard. The above total costs include the construction of a transformer and meter house in Harvard for a small local business.

Cost and Operating Data on 6,600-Volt Lines. Electrical World, July 3, 1915, gives the following data from a paper on distribution conditions presented at the recent convention of the National Electric Light Association by J. C. Martin and relate to two 6,600-volt rural-service lines now in operation in the State of Washington. The first case is that of a line about 17.5 miles long, on which there are thirty-two telephone and railway crossings, and the second case is that of a line about 14.5 miles long on which there are nine telephone and railway crossings. These lines were built with the expectation of developing new business in the future and with the knowledge that the return in the first few years of their life would perhaps not be sufficient to pay all charges.

TABLE XXIX. REPRESENTATIVE LINE-CONSTRUCTION COST ITEMS, HARVARD, MASS., CONDITIONS, 1912

3 13,000-volt disconnecting switches	$17.60
1 5-amp. 2300-volt single-pole line switch complete with eight day clock	23.35
1 double-pole horn-gap arrester	4.56
2 single-pole, single-throw knife switches	1.42
2 eight-point receptacles and four-point plugs; one ammeter plug	11.10
1 9.95-kva automatic induction regulator	670.85
3 15-kva. transformers, 13,200 to 2,200 volts, 60 cycles	435.00
16 5/8-in. by 5-in. machine bolts	0.83
16 1/2-in. by 3-in. lag bolts	0.30
100 1 1/2 B. & D. single-wire cleats	3.00
500 ft. No. 14 single-braid, rubber-covered wire	4.13
90 lb. No. 00 weatherproof wire	12.68
4 2300-volt primary cut-outs with plugs	2.71
523 six-pin cross-arms	351.61
98 eight-pin cross-arms	81.95
254 four-pin cross-arms	111.84
72 5/8-in., 6-ft. guy anchor rods	21.25
5000 ft. 5/16-in. seven-strand guy wire	32.65
1200 ft. 1/4-in. seven-strand guy wire	6.36
228 guy thimbles	5.92
36 two-bolt guy clamps	2.31
196 three-bolt guy clamps	10.34
12 tree blocks	0.72
390 5/8-in. by 12-in. machine bolts	20.16
102 5/8-in. by 14-in. machine bolts	6.00
22 5/8-in. by 8-in. eye-bolts	2.28
261 5/8-in. by 16-in. spacing bolts	22.96
12 5/8-inch. by 22-in. spacing bolts	1.74
8 1-in. by 14-in. galvanized rock eye-bolts	3.28
2830 2 1/4-in. by 2 1/4-in. by 1/4-in. square-cut washers	28.08
1494 3/8-in. round-cut washers	2.71
130 7-ft. alley-arm braces	97.50
744 pairs cross-arm braces	90.76
960 13,000-volt No. 2 Crown insulators	131.52
55 No. 14 Electrose strain insulators	36.03
6 No. 270 Victor insulators	5.86
5068 locust cross-arm pins	73.33
42 No. 14 Pierce steel-clamp pins	4.54
42 galvanized-iron insulated clamps	29.57
259 30-ft. poles	906.50
338 35-ft. poles	1,859.00
23 40-ft. poles	172.50
8 45-ft. poles	72.00
35 street series brackets	187.70
1 pole-line switch	51.00
26 compression-type multigap arresters	77.45
22,840 lbs. No 6 triple-braid weatherproof wire	3,982.28
463 lbs. No. 8 triple-braid weatherproof wire	87.55
7380 lbs. No. 8 duplex metal wire	55.65
6980 lbs. No. 6 medium copper wire	1,169.15
160 lbs. No. 6 soft-base wire	28.32
175 ft. two-conductor cable, No. 10	27.81
248 lbs. No. 4 bare copper wire	50.34
3 No. 61 Beardsley break arms	1.02
43 No. 220 Pierce brackets	12.47
12 copper sleeves for No. 6 to No. 4 wire	4.42
27 copper sleeves for No. 6 to No. 6 wire	2.97
Services of construction foreman, 74 days at $4.17	308.58
Services of superintendent, 10 days at $5.77	57.70
Labor cost	5,429.58

The figures shown do not take into account the cost of energy lost between power house and customer and, therefore, show a loss that is less than the actual. The losses shown in these cases, it is stated, are typical of those that are likely to be sustained in the early life of very many similar lines in the rural territory of Western States.

TABLE XXX. COST OF 17.5-MILE, 6,600-VOLT LINE — THIRTY-TWO CROSSINGS

Actual cost of line	$26,463.00
Additional cost for crossing construction, 1911 N.E.L.A. specifications	2,553.28
Total	$29,016.28
Actual annual revenue	$4,350.35
Operation and fixed charges:	
(a) Line as built:	
Depreciation (average 5.2%)	$1,378.15
Operating	948.86
Maintenance	194.94
Taxes	105.63
Interest, 8%	2,117.04
Total operating cost for year	$4,744.62
Loss per year	$394.27
Loss in per cent. of actual cost of line	1.49
Loss in per cent. of annual revenue	9.10
(b) With crossing construction included:	
Depreciation	$1,531.35
Operating	948.86
Maintenance	194.94
Taxes	105.63
Interest, 8 per cent.	2,321.30
Total operating cost for year	$5,102.08
Loss per year	$751.73
Loss in per cent. of actual cost of line, plus crossing construction costs	2.6
Loss in per cent. of annual revenue	17.3
Number of crossings	32
Total estimated cost of crossing construction	$2.533.28
Average cost per crossing	$79.79

TABLE XXXI. COST OF 14.5-MILE, 6,600-VOLT LINE — NINE CROSSINGS

Actual cost of line	$18,829.00
Additional cost for crossing construction, 1911 N.E.L.A. Specifications	886.86
Total	$19,715.86
Actual annual revenue	$3,727.45
Operation and fixed charges:	
(a) Line as built:	
Depreciation (average 5.35%)	1,006.31
Operating	1,006.95
Maintenance	245.20
Taxes	90.77
Interest	1,506.32
Total operating cost per year	$3,855.55

Loss per year	$128.10
Loss in per cent. of actual cost of line	0.68
Loss in per cent. of annual revenue	3.44

(b) With crossing construction included:

Depreciation	$1,069.48
Operating	1,066.95
Maintenance	245.20
Taxes	90.77
Interest	1,577.27
Total operating cost	$4,049.67

Loss per year	$322.22
Loss in per cent. of actual cost of line, plus crossing construction costs	1.63
Loss in per cent. of annual revenue	8.65
Number of crossings	9
Total estimated cost of crossing construction	$886.86
Average cost per crossing	$98.54

Cost of Construction a Short 11,000-Volt Transmission Line. With the extension of central-station service into rural territory the construction expense of moderate voltage transmission lines becomes of interest. The accompanying cost data given in Electrical World, May 15, 1915, are from the construction sheets of a Massachusetts central station which recently built an 11,000-volt single-phase transmission line across a portion of Cape Cod 8.1 miles long, pole location rights being secured from real-estate owners en route:

539 35-ft. poles, at $6	$3,234.00
1204 Victor insulators, at 20 cts.	240.80
539 pair braces, at 26 cents each	140.14
11,843 lbs. bare copper wire, No. 4, at 16.75 cts.	1,983.70
Carting poles	650.00
130 guys, at $1.14	148.20
424 lb. No. 6 bare wire, at 18 cts.	76.32
1095 two-pin cross-arms, at 40 cts.	438.00
2190 1½-in. by 12-in. locust pins, at 4 cts.	87.60
2 transformer towers	348.00
5 11,000-volt lightning arresters, at $43.50	217.50
2 11,000-volt air-break switches, at $100	200.00
1 2,300-volt oil switch	89.20
Right-of-way	345.00
Freight	183.00
Labor	4,800.00
Total	$13,181.46
Per mile of line	$1,620

The company obtained the permits for running the wires and also for the pole locations, the erection work being by contract. The contractor trimmed all poles, which averaged 125 ft. in spacing. Poles were head-guyed every half-mile, all guys being provided with porcelain insulators, and every twelfth pole was double-armed. Tree trimming was done by the contractor.

Cost of 11,000-Volt 3-Phase Transmission Line. H. W. Garner gives the cost of constructing a 11,000-volt 3-phase line, 16 miles long, on steel tripartite poles, as $982 per mile.

Cost of 19,000 Volt Transmission Lines in New England. The

following costs cover the recent construction of transmission lines by the Connecticut River Power Company in New Hampshire and Vermont, as given in Electrical World, July 17, 1915. One line was built from Brattleboro to Bellows Falls, Vt. The poles used were standard class B chestnut, with wish-bone arms and 10-in. disc insulators carrying three No. 2 three-strand copper wires for operation at 19,000 volts. A No. 6 copper telephone circuit was installed on steel cross-arms, with a special side bracket on alternate poles for transpositions. Each pole was provided with a metal cap, from which the ground wire runs to the bottom of the pole. Construction costs for 21 miles of the line are as follows:

Rights-of-way, surveys, etc.	$23,181.32
Clearing right-of-way	7,281.72
Tools	657.72
Hauling and delivering	2,977.94
Excavation	2,556.43
Setting and guying, framing and treating	4,796.98
Placing insulators and stringing wires	1,955.31
Poles	4,926.90
Wire	14,881.49
Insulators, pins, arms and hardware	6,872.73
Engineering, supervision, and general charges	4,890.00
Transformers and switch equipment	5,415.98
Interest during construction	2,400.00
Total	$82,794.52

Another line of the same construction known as the Vernon Station-Massachusetts line, 8.5 miles long, has also been built recently and the following costs cover its construction details:

Lands and rights-of-way	$17,387.50
Tower-line construction	28,038.92
Switches and special construction at power house	11,507.10
Engineers' and contractors' fees *	5,931.90
Legal expense, office expenses, taxes and miscellaneous	1,784.58
Interest during construction	3,000.00
	$67,650.00

* Represents the overhead expense of the contractor. The line was built on a flat-fee basis, by the Power Construction Company.

Method and Cost of Erecting 20,000-Volt Transmission Line Towers in Assembled Condition by Means of Gin Poles. The following is condensed from an article by W. R. Strickland in Electrical World, June 13, 1908. The towers were built to carry two three-phase 20,000-volt circuits of No. 4 hard-drawn copper wire, the insulators being triple petticoated and tested to 60,000 volts. A ground wire is placed in the center on the upright pipe for lightning protection, and two telephone wires are carried on insulators mounted within the steel pole structure. They are of structural steel heavily galvanized, and were shipped in bundles, most of which could be handled by four men. There were four similar pieces for one tower, the large cross arm and the pipe for ground wire, being very heavy, were shipped separately. The towers were assembled

in the field with bolts and nuts heavily galvanized over the threads. The net weight of each standard tower is 2,200 lbs.

Several methods of erection were considered, the most popular suggestion being the movable A-frame. This method, as well as others, could not be used for several reasons. The center of gravity of the towers is very high, and the steep slopes upon which they had to be erected would have made it necessary for the A-frame to work at right angles to the line, in which case the tower would have had to be turned after erecting owing to the necessity of assembling it with the cross arm lying flat upon the ground. Some of the hills were so steep that the towers had to be cut away to fit before erection, and separate concrete anchorages were used for laterals and horizontal braces. There were few level spots. The weight of an A-frame would have been too great in one piece, as it had to be carried by hand from tower to tower, because of the broken character of the country. Moreover, the bottom legs of the tower were too flexible for the weight thrown on them sideways during election in a manner not contemplated in the design. While the lateral braces were large enough for the tension which will come on them after erection by reason of the pull due to wind pressure, they could not carry the compression which would have come on them in resisting the stresses developed by the eccentric loading at the end of the leg during erection.

As a result of these conditions peculiar to the tower and the country, the following method was employed for application by an American general foreman, all of the rest of the labor, with one exception, being Porto Rican.

One gang in charge of a Porto Rican engineer dug the holes, put in the concrete footings, and cut off or lengthened the lower legs to correspond to the slope of the hillside. Another gang assembled the towers with the exception of the lower leg pieces, while another gang erected the small gin-pole. Then came the main erecting gang carrying large gin-poles, blocks, tackle, dead-men, tools, etc. The small gin-pole being in place, the last gang quickly erected the first large gin-pole, which in turn was used to erect the second.

The most difficult problem at each tower was the anchoring of the many guy lines needed. For this purpose trees were occasionally used, but in most cases steel dead-men had to be driven in the ground; in some cases the ground was so soft that two dead-men had to be used. The erecting of the main poles was in charge of a mate from a Porto Rican sailing vessel, as sub-foreman, his principal assistants being six sailors whose carefulness and good judgment were such that only twice did the gin-pole break away.

At each angle point, the tower was set to bisect the angle in the transmission line, a supporting guy being held by concrete anchorage. Four or five towers were erected per day. After the men had gained a little experience the cost of erection, including all labor and material, sub-delivery of towers and concrete, cement at $3.50 per barrel at the tower, assembling, erecting and concrete footings and casing, was brought down to from $25 to $27 per

tower. Owing to special work, and some towers in exceptionally bad locations, which required more care and more concrete, and owing to delays caused by right of way fights, the average cost was considerably higher. Each common laborer was paid 75 cts. per day, the sub-foreman receiving $2 or $3.

Method and Cost of Constructing 22,000-Volt Iron-Wire Steel-Poles Transmission Line. M. D. Leslie in Electrical World, Feb. 10, 1917, gives the following data on the methods and cost of constructing a 22,000-volt, 3-phase, 60 cycle transmission line of relatively inexpensive type.

The line as constructed consists of three No. 6 E. B. B. galvanized iron wires mounted horizontally 4 ft. apart on steel arms. Bates expanded steel poles, 4 in. diam. and 30 ft. long, set in concrete 300 ft. apart, and head guyed both ways in the direction of the line every half mile are employed except at railroad crossings, where 35 ft. poles are used. At corners and crossings the poles are double-armed.

Experiments were carried on to determine the most satisfactory way of setting the poles in concrete. The manufacturers of the poles supply H-shaped forms, which require about 2 ft. of concrete. The form itself requires a hole about 17 in. in diameter, but the ordinary hole digger cannot be depended upon to center the hole exactly, so it is necessary to dig a much larger hole in order to "line up" the poles properly. It was also found difficult to place concrete in such a small form at the bottom of a hole. Old-fashioned posthole diggers were then tried. Two holes were dug side by side and joined, thus giving a hole about 6 in. by 12 in. in cross-section. This method of construction was satisfactory in some soils, but was abandoned in favor of digging with ordinary tools, which were trimmed down on the sides so that a small rectangular hole could be made. These holes were easily dug, and required from 5 to 6 cu. ft. of concrete to the pole.

Cross-arms were distributed with the poles, and a definite quantity of sand left at each pole. The cement was stored along the way, a day's supply being carried by the pole-raising gang. From two to five diggers were employed, according to the nature of the ground. The assemblers were accompanied by a wagon, in which was carried all the necessary material, including insulators.

At the time the line was built it was very difficult to get labor of any kind. Consequently it was necessary to work part of the time with a "short" crew, and to leave the wire stringing for the return trip. A cook shack was maintained for feeding the men and tents provided for them to sleep in. The camp was moved along as the work progressed.

A full raising crew consisted of a driver, two concrete mixers, a "jinney" man, four "pikers" and a foreman. The outfit which was used consisted of one team, a water tank and a sled. The cement was carried on the tank and the sled served to carry the tools from pole to pole and as a mixing box for the concrete. The concrete was usually mixed by the time the pole was set. The poles were raised by ordinary methods, plumbed with a level and

tamped in. Poles tamped in with the concrete were stable enough to be left at once. An oval form, 4 in. deep, was made to shape the base above the top of the ground. While the majority of the gang moved up along the line to the next pole site, one man stayed behind to trowel off the top of the base and remove the form for use on the next pole. The best day's work by the raising gang was to set 34 poles in 11 hrs.

The guying and stringing was done on the return trip. Two men dug the slug holes and set the concrete slugs. Two men with a single-horse wagon installed the guys. Four linemen and a teamster did the stringing and tying in. Three coils of wire were distributed every ⅓ mile and picked up by the stringing gang. All three wires were strung at one time from reels mounted on a wagon. The wire was pulled at intervals of about 1 mile, using permanently guyed poles. The usual high-tension tie of No. 8 iron wire was employed on this line.

Five-inch neck-soldered Western Union splices were used, soldering being done with a pot and ladle. Sample splices made by different linemen gave the following results under test:

Sample	Maximum strength (lbs.)	Cause of failure
1	1,850	Splice slipped
2	1,870	Wire broke, splice held
3	1,810	Wire broke, splice held

The line has been in satisfactory operation for about three months with five interruptions, caused by an insulator being shot off in one case, a wire thrown onto the line in two others, and broken wires, due to defects in the wire itself, in the remaining cases.

The item of engineering given in Table XXXII includes considerable of the writer's time and expenses as well as those of the surveyor. The item of total labor includes all labor, of all classes,

TABLE XXXII. DISTRIBUTION OF TRANSMISSION LINE COSTS

(Distance Dodge City to Bucklin, Kan., approximately 31 miles.)

	Total	Per Mile
Engineering and survey	$828.50	$26.73
Pole rights	238.30	7.69
Total labor	2,619.59	84.50
Camp expenses and meals	592.54	19.11
Teaming	717.49	23.15
River sand, gravel and cement	356.81	11.51
Insulators	840.03	27.10
Pins	469.30	15.13
Wire (95 miles No. 6 EBB)	3,368.93	108.67
Steel poles (total, 557, including twenty-three guy stubs)	7,856.31	253.43
Guying material	380.31	12.27
Wood poles and line material	287.90	9.28
Transformers, switches and arresters	2,739.63	88.37
Substation material	193.11	6.23
General expense	107.25	3.46
Total	$21,596.00	$696.64

Distribution of labor

Rebuilding of wood-pole line in town to accommodate high-tension line from city limits to plant	$391.30
All work connected with setting 539 steel poles ready for wire	1,133.95
Stringing wire setting anchors and attaching guys to above poles (about 29 miles of line)	470.64
Building towers and finishing up last mile of steel line	623.30
Total	$2,619.59

including the foreman on the job, with the exception of some of the teamsters who were hired at a flat rate per day with their teams and wagons. The item of camp expenses is the net cost after deducting the amount charged the men for meals. Laborers were paid 25 cts. per hr. and linemen 40 cts. per hr. and all were charged 20 cts. per meal, which amount covered less than half the cost. The item of teaming includes all expense of teams for hauling various materials and carrying on the work, a charge being made for the use of company teams, as well as those hired.

Labor expenses are distributed in the lower part of the table, so that the actual cost of pole setting is shown. This line, like most others, had special features which made it expensive. One of these was the rebuilding of about a mile of wood pole line in order to provide a connection with the power house where the transformers are located. The other condition that affected the installation cost was the finishing up of the last mile on the Bucklin end at a later time with a small crew. This was made necessary by a lack of necessary material, and the expense was entirely out of proportion to the work done. Some of the men on this section of the line also built towers, so it is not possible to give an accurate division of this labor.

The expense given for setting 539 steel line poles and the necessary guy stubs includes all labor connected with such work as digging holes, assembling arms, pins and insulators, setting poles and concreting their bases, as well as the foreman's time and other labor that was paid for.

Cost of Constructing Wooden Towers for a 60,000-Volt Transmission Line 25 Miles Long. The method of constructing the 60,000 volt wooden tower line of the California-Oregon Power Co., which involved several interesting and novel features, is described by Mr. O. G. Steele in the Journal of Electricity Power and Gas for May 4, 1912. The details of the tower are shown by Fig. 20. Spans vary from 450 to 1,000 ft., one span being 1,465 ft. across Jennie Creek canyon.

Cast iron anchor plates were used in the foundation work while 3 in. channel iron was employed for the cross-arms. These arms are 16.6 ft. long and are painted with P. & B. paint to prevent rusting. Angle iron 2.5 x 2.5 ins. was used to bind the poles to the concrete bases shown in the illustration. Insulators of the Locke suspension type are employed. Each insulator, composed of three units, clasps the conductor by means of a straight line clamp. At

the point where angles are necessary in the transmission line four units are employed in the insulator.

Every fifth tower is so constructed as to take up the strain; at these strain towers four anchors are employed with guy wires crossed, while for standard towers only two anchor plates are employed.

Raising the towers proved an interesting problem, due to the roughness of the country. While the hillside, composing a portion of the transmission line, made only one method applicable, it was not at all times practicable to deliver the tools required. A crew of 12 to 15 men was employed.

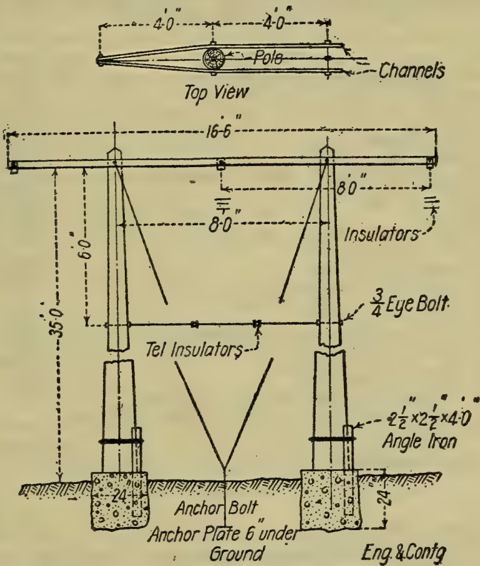


Fig. 20. Details of wooden tower for high tension transmission line.

The poles were first placed on supports about 7 ft. above the ground. The guy wires were next passed over the fork and with the aid of a block and tackle the poles were pulled into place, during which process men with pike poles guided the poles. After the poles were set on their bases the guys were pulled through the eye of the anchor row and tightened by hand and another crew following put the guy wires in final taut condition.

Later in the progress of the work it was found that a horse could be used to raise the towers and this method proved satisfactory. As many as 25 of these towers may be thus raised in

one day. Referring to the guy clamps, the ordinary three-bolt galvanized type was employed, but in the future the combination clamp will replace the three-bolt design.

An average of 10 towers per mile were necessary in the construction of the transmission line, although this varied somewhat wherever rolling country prevailed. Thus in crossing canyons, spans were made of full length in most cases.

The cost of construction is estimated from the unit costs to be about as given in Table XXXIII, assuming 10 towers per mile.

TABLE XXXIII. AVERAGE COST PER MILE OF WOOD TOWER TRANSMISSION LINE. 10 TOWERS PER MILE, 24.6 MILES

Materials:		
Wire 3 No. 2 copper, 3,242 lbs.	$0.155	$502.51
Wire 2 No. 9 iron, 1,053 lbs.	.05	52.65
Insulators, 100 suspension units	.775	77.50
33 suspension eyes	.125	4.13
7 strain clamps	.74	5.18
30 straight line clamps	.364	10.91
Channel iron arms, 10 sets of 2,132 lbs.	.033	43.56
Angle iron, 338 lbs.	.0298	10.00
Cement, 4.35 lbs.	3.74	16.30
Gravel, 6.3	.25	1.57
Telephone insulators, 21 No. 26	.05	1.05
Pole line hardware —		
24 bolts, ⅝ x 8 ins.	.088	20.00
20 bolts, ⅝ x 1¾ ins.	.0368	7.72
50-3 bolt ⅜-in. guy clamps	.151	7.55
50 ½-in. thimbles	.0312	1.56
250 ft. ⅜-in. strain guy cables	.016	40.00
25 guy rods, ½-in. x 6 ft.	.36	9.00
450 lbs. anchor plates	.03658	16.36
Poles, 20 40-ft. red fir	1.629	32.58
Right of way, average cost of securing	.....	16.85
Camp outfit and tools, proportional cost per mile	.....	20.00
Total materials	.....	$896.78

Labor:	
Surveying right of way	$ 64.00
Clearing right of way	148.20
Hole digging, 20 foundation holes, 2 ft. deep, and 25 guy holes, 5 ft. deep	79.00
Powder	6.95
Tower framing, 10 towers, at $2.29	22.90
Haulage, including cost of teams, hay and grain; 20 poles, average 2 miles, at $3.037	60.74
Wire, average cost per mile	20.51
Channel iron arms, including painting	14.50
Foundation materials	25.80
Setting 20 foundations (conc.), at $5.51	110.20
Raising 20 towers, at $5.538	110.76
Wire stringing 3 copper transmission and 2 iron telephone	73.60
Extras, blacksmithing, coal and labor	10.00
Warehouse man	4.00
Time-keeping and books	14.00
Superintendence	28.50
Total labor	$ 783.66

Miscellaneous:

Camp expense, moving, depreciation in maintenance of automobile	$ 86.00
Loss on cook house after serving 14,930 meals at 35 cts.	7.56
Numbering, repairing and distributing material for future repairs	25.80
Total miscellaneous	$ 119.36
Total cost per mile, complete	$1,799.80

Cost of 66,000-Volt Transmission Line. An extended discussion of the cost of a 66,000-volt transmission line was a feature of a recent hearing given by the Massachusetts Gas and Electric Light Commission to the Turners Falls Power & Electric Company, of Greenfield, Mass., is abstracted in Electrical World, Apr. 10, 1915. The line was built from Turners Falls to Springfield, Mass., and is 42.88 miles long. It is designed for ultimate service at 110,000 volts, and the total cost is shown in the following table:

Clearing right-of-way	$13,898
Contractors' general expense	9,151
Transportation of materials	6,072
Excavation for standard anchors	14,913
Setting standard anchors	10,443
Steel towers	73,526
Assembling and erecting towers	22,861
Insulators installed	20,536
Wire	127,122
Hardware	6,557
Changes in line	6,803
	$311,882
Special river crossings	35,218
Special towers at substations	2,627
Special concrete footings	13,057
Grand total	$362,784

The first section above totaled covers the so-called standard construction used on the line and figures $7,296.68 per mile, or $672.16 per tower. The total cost, including special work as listed but not including real estate and right-of-way, was $8,465.11 per mile, or $781.86 per tower.

The line was built by F. T. Ley & Company, Springfield, Mass. The power company bought the material, furnished the towers, wire and insulators, and purchased the right-of-way. The right-of-way is 150 ft. wide and cost about $250 an acre. Since the line was built, about a year ago, the right of eminent domain has been granted to transmission companies in Massachusetts, which would unquestionably have greatly reduced the cost of the right-of-way had it been operative during the preliminary period. Where the line traverses level and fairly firm soil the towers are secured by anchors 7 ft. long with 1-ft. cross-pieces, set in the earth, one anchor being provided at each corner of the tower. At railroad crossings, marshy and wet places the anchors are installed in concrete legs about 2 ft. square and 8 ft. deep, except where the towers are lifted considerably above the ground level. One such concrete footing is used at each leg of an angle tower in crossing the West-

field River, and for 2 miles between the Agawam substation and Springfield. Across this portion of the line the country is flooded from 5 ft. to 15 ft. deep in the spring.

There are three special river crossings, where the towers cost $1,250 apiece at the factory and are 100 ft. high. It cost from $1,000 to $1,200 to erect these on the ground. The foundations cost from $1,800 to $2,500 each for these crossings, except where the line crosses the Connecticut River and enters Springfield. Here the cost was $4,000. Copper-clad steel wire is used on the long spans. The item "contractor's general expense" includes the cost of maintaining camps, transportation of general superintendents, etc. "Changes in line" covered relocations in the field after a portion of the construction was in. From Turners Falls to Amherst heavy timber was encountered. The total cost of the right-of-way was $200,695.

Excluding right-of-way and not including special river crossings and concrete footings, the line cost $7,296.68 per mile, or $672.16 per tower, compared with $8,280 per mile and $900 per tower on similar lines built in the same general territory. The Turners Falls towers weigh about 4000 lbs. each, compared with 5700 lbs. for the standard towers of an adjacent system. River-crossing towers were built of structural steel and riveted on the job, the standard towers being only bolted together. The neighboring system (Connecticut River Transmission Company) spaces its towers 9.2 per mile and uses No. 00 wire, compared with a spacing of eleven per mile and No. 0 conductor on the Turners Falls system. The former also uses six suspension insulator disks per wire, while the latter employs four, costing $1 per disk. Each tower carries two three-phase circuits, and the standard towers are approximately 75 ft. high and about 17 ft. square at the base. To change the line for 110,000-volt service the only alteration necessary on the line proper will be the addition of insulator disks.

Cost of Erecting 110,000-Volt Transmission Lines. Electrical World, June 7, 1913, gives the following labor costs on four different 110,000-volt lines in this country. All are six-wire, two-circuit tower lines on standard suspension insulators arranged on either side of standard Millikan towers spaced ten to the mile. None of the towers possesses concrete footings, but connecting the top of each in all cases is a Siemens-Martin stranded-steel ground wire. The costs included everything except general office expense and supervision, which should not exceed $50 a mile. Of course, the cost of the towers, insulators, wires and right-of-way is not included; neither is the cost of clearing the right-of-way. The figures given include wages, commissariat, team hire and transportation of material from the railroad to the right-of-way.

Line No. 1 passes through a high grade of country, necessitating more stub holes, angles and guying than Line No. 2, which passes through a wooded section most of the way. It will be noticed that the cost of distributing and stringing the wire in Line No. 1 is greater than in Lines 2, 3 and 4. This is due to the fact that only

one three-phase line was operated at first, the other three-phase line having been strung afterward and while the first line was alive. In some of the more recent lines erected in this country, notably that of the Central Georgia Power Company, the insulators were attached to the towers before the latter were hoisted into position so that a saving in the fifth item, "hanging insulators," would be effected. All of the lines traverse fairly rolling country, dotted here and there with heavily wooded sections, and copper is used as a conductor for the most part, although sections of lines No. 3 and 4 are of aluminum. None of the lines parallels any railroad system for any distance, and the distribution cost has been approximately $5 a tower. Where concrete footings are provided for the towers, a practice which obtains in many transmission systems, the labor costs are considerably increased.

TABLE XXXIV. COST PER MILE OF ERECTING TWO-CIRCUIT, 110,000-VOLT TOWER LINES

Operation	Line No. 1, 49 miles	Line No. 2, 34 miles	Line No. 3, 129 miles	Line No. 4, 181 miles
Distributing towers	$47.16	$48.48	$49.15	$53.68
Assembling towers	92.66	101.23	94.79	98.06
Erecting towers	77.90	75.15	70.44	77.77
Digging stub holes	99.93	23.10	27.67	54.36
Hanging insulators	55.53	32.04	42.00	44.72
Distributing wire	48.84	17.21	27.20	30.84
Stringing wire	202.29	107.62	124.35	150.53
Digging holes for towers	169.59	143.23	156.79	166.00
Total per mile	$793.90	$548.06	$592.39	$675.96

Cost of Line Materials. From data recently prepared by the Amesbury, Mass., Electric Light Company covering 13,200-volt line material costs since Jan 1, 1917, the following extracts are printed. The figures reflect the present high levels of equipment prices among small companies. Besides being interesting in connection with making estimates they have record value:

Quantity	Items	Cost
158	30-ft. poles, chestnut, B	$727
24	35-ft. poles, chestnut, B	146
20	40-ft. poles, chestnut, B	165
8	45-ft. poles, chestnut, B	88
8	50-ft. poles, chestnut, B	136
287	2-pin cross-arms (special)	172
4	4-pin cross-arms	5
8	8-pin cross-arms	17
15,223 lbs.	No. 2 bare H. D. copper wire	5,147
373 lbs.	No. 4 bare S. D. copper wire	137
381 lbs.	No. 2 bare stranded copper wire	137
532 lbs.	No. 2 W. P. wire	147
500 ft.	½-in. 7-strand guy wire	7
5,250 ft.	5/16-in. 7-strand guy wire	89
850 ft.	7/16-in. 7-strand guy wire	15
50	No. 58,160 line wire protectors	210
100	No. 2 copper splicing sleeves	32

Quantity	Items	Cost
90	6-ft. anchor rods	$53
19	Anchor planks	7
356 ft.	12-in. by 2-in. spruce planking	15
10 gals.	Creosote	6
4	600-kw., 13,200/2200-volt transformers	7,550
6	300-amp., 13,200-volt choke coils	229
2	3-phase, 13,200-volt lightning arresters	752
6	300-amp. 13,200-volt disconnecting switches	60
Setting	200 poles (by contract)	3,770

TABLE XXXV. ANCHOR OR GUY RODS

Diam., ins.	Length, ft.	Weight, lbs. per 100	Price per 100
½	5	295	$16.50
½	6	340	18.35
½	7	395	21.00
⅝	4	415	21.00
⅝	5	500	23.00
⅝	6	590	25.50
⅝	7	680	29.25
⅝	8	770	33.00
¾	4	595	27.35
¾	5	730	32.25
¾	6	840	36.75
¾	7	950	42.00
¾	8	1,080	47.25
¾	9	1,210	52.50
1	8	2,350	90.75
1	10	2,900	108.00
1¼	10	4,650	181.50
1½	12	7,950	305.25

Prices do not include washers.

Galvanized anchors cost 30 to 35% more and on lots of 500 to 1,000 is a discount of 10%.

TABLE XXXVI. MATTHEW'S SPECIAL GUY ANCHORS

Diam. anchor, ins.	Weight, lbs. per 100	Price per 100
5	250	$42
6	450	75
5	650	69
6	1,000	135
7	1,500	270
8	3,800	450
10	5,000	675
12	8,000	900

Diameter of rods for above anchors are as follows: 5 in. anchor has .5 in. rod, 6 in. a .625 in. rod, 7 in. a .75 in. rod, 8 in. a 1.125 in. rod, 10 in. a 1.25 in. rod, and 12 in. a 1.5 in. rod.

Galvanized anchors cost 20 to 30% more than those given.

TABLE XXXVII. BOLTS FOR DOUBLE CROSS ARMS

Diam. ins.	Length, ins.	Weight, lbs. per 100	Price per 100
½	12	86	$5.60
½	14	93	6.15
½	16	100	6.65

Diam., ins.	Length, ft.	Weight, lbs. per 100	Price per 100
½	18	107	$7.10
½	20	115	7.50
½	22	123	7.90
⅝	12	129	8.55
⅝	14	143	9.15
⅝	16	157	9.75
⅝	18	171	10.35
⅝	20	186	10.95
⅝	22	201	11.55
⅝	24	216	12.15
⅝	26	231	12.75
¾	14	198	12.00
¾	16	219	12.75
¾	18	240	13.50
¾	20	261	14.25
¾	22	282	15.00
¾	24	324	15.75

Prices include 4 nuts, but no washers.

Galvanized bolts cost 30 to 35% more. Lots of 500 to 1,000 have a discount of 10%.

TABLE XXXVIII. BOLTS AND LAG SCREWS

	Price per 100		
Length, ins.	¼-in.	¾-in.	1-in.
3½	$1.17	$2.40	$5.00
4	1.25	2.55	5.25
4½	1.33	2.70	5.50
5	1.40	2.85	5.80
6	1.58	3.20	6.40
7	1.73	3.50	7.00
8	1.82	3.85	7.60
9	2.05	4.10	8.20
10	2.25	4.45	8.75
11	2.40	4.70	9.30
12	2.60	5.00	9.90

	Price per 100		
Length, ins.	⅜-in.	½-in.	¾-in.
4	$0.74	$1.22	$2.86
5	0 83	1.36	3.15
6	0.92	1.52	3.50
7	1.22	1.65	3.75
8	1.34	1.80	4.25
9	1.45	1.95	4.50
10	1.55	2.20	4.75
12	1.75	2.40	5.25
14	1.90	2.70	5.90
15	2.05	2.85	6.25
18	2.40	3.25	7.20
20	2.60	3.50	7.75

Cost of Lead Covered Telephone Cable. Prices of 19 and 22 gauge lead covered cables based upon the 10 year average cost of materials immediately preceding the Great War were as follows:

Copper	15.4	cents per pound
Lead	4.6	" " "
Tin	36.5	" " "

TABLE XXXIX. WEIGHTS AND PRICES — SINGLE, FLAT DUPLEX AND TRIPLEX LEAD COVERED, INSULATED CABLES

Size of wire, B. & S. gauge or No. of cir. mils.[1]	Number of conductors	Thickness of insulation on each conductor, ins.[2]	Thickness, lead sheath, ins.	Working voltage	Weight, per ft., lbs.	Price per ft., cents. (Lead taken at 5 cts. per lb.) Base price of Copper 14c.	16c.	18c.
# 4s.	2	4/32 V. C.	7/64	2,300	1.87	16.2	16.8	17.3
# 6s.	1	4/32 V. C.	3/32	2,300	0.89	7.68	7.86	8.03
250,000	2	4/32 V. C.	1/8	2,300	4.78	30.7	40.8	54.2
500,000	2	4/32 V. C.	1/8	2,300	7.20	78.5	85.1	91.8
500,000	1	3/32 V. C.	7/64	600	3.59	39.0	42.4	45.7
1,000,000	1	7/64 V. C.	1/8	600	6.26	71.0	77.7	84.4
1,500,000	1	4/32 V. C.	1/8	250	8.48	100.8	110.8	120.9
1,000,000	1	7/64 V. C.	1/8	250	6.26	71.0	77.7	84.4
1,000,000	1	3/32 P.	1/8	250	6.15	65.4	72.1	78.7
750,000	1	3/32 P.	7/64	250	4.71	49.9	54.9	59.9
500,000	1	3/32 P.	7/64	250	3.59	36.2	39.5	42.9
300,000	1	3/32 P.	7/64	250	2.62	24.7	26.7	28.7
500,000	1	7/64 P.	7/64	600	3.68	36.7	40.0	43.4
1,000,000	1	7/64 P.	1/8	600	6.26	65.9	72.6	79.2
500,000	2	5/32 P.	1/8	2,300	7.86	76.0	82.6	89.3
250,000	2	5/32 P.	1/8	2,300	5.08	44.7	48.0	51.3
# 4s.	2	5/32 P.	7/64	2,300	2.11	15.7	16.2	16.7
# 6s.	1	5/32 P.	3/32	2,300	1.00	7.60	7.78	7.95
250,000	3	13/64 P.	1/8	13,800	9.92	83.0	87.9	92.8
500,000	1	N.E.C.R., T.	7/64	250	3.68	42.2	45.6	49.0
350,000	1	N.E.C.R., T.	7/64	250	2.96	32.5	34 9	37.2
300,000	1	N.E.C.R., T.	7/64	250	2.71	29.1	31.1	33.2
250,000	1	N.E.C.R., T.	7/64	250	2.44	25.8	27.4	29.1
# 0	1	N.E.C.R., T.	3/32	250	1.37	13.8	14.5	15.3
# 1	1	N.E.C.R., T.	3/32	250	1.24	12.2	12.8	13.3
# 6	3	N.E.C.R., T.	7/64	250	1.93	18.44	18.96	19.49
#12s.	3	N.E.C.R., T.	3/32	250	0.98	8.98	9.12	9.25
500,000	1	N E.C.R., T.	7/64	600	3.68	42.2	45.6	49.0
250,000	1	N.E.C.R., T.	7/64	600	2.44	25.8	27.4	29.1
#1	1	N.E.C.R., T.	3/32	600	1.24	12.2	12.8	13.3
#4/0	2	7/64 R., T.	1/8	2,300	4.35	45.4	48.2	51.0
#18s.	3	7/64 R., T.	3/32	2,300	1.42	11.79	11.84	11.93

1 All conductors are stranded except where indicated as being solid by the letter S.

2 V.C.— Varnished cloth, P.= paper; R. T.— New code rubber, taped.

TABLE XL. COST OF LEAD COVERED CABLE

Number of pairs of conductors	Weight per ft., lbs.	Price per ft.
	22 B. and S. Gauge	
5	0.49	$0.046
15	0.745	0.071
30	1.02	0.101
60	1.45	0.157
100	2.12	0.236
120	2.48	0.273
180	3.10	0.368
200	4.06	0.455
400	6.21	0.768
600	8.31	1.049

Number of pairs of conductors	Weight per ft. lbs.	Price per ft.
	19 B. and S. Gauge	
15	0.970	$0.097
30	1.39	0.146
60	2.22	0.180
90	2.81	0.350
120	4.21	0.475
180	5.44	0.644
300	7.59	0.966

TABLE XLI. CROSS ARMS

Cross-section, ins.	Weight per lin. ft., lbs. Fir	Yellow pine	Cents per lin. ft.
2¾ x 3¾	2.50	3.25	10.00
3 x 3¾	2.70	3.60	10.83
3 x 4	3.00	3.90	11.51
3 x 4¼	3.20	4.10	12.18
3¼ x 4¼	3.40	4.40	13.12
3¼ x 4½	3.75	4.70	13.85
3½ x 4½	4.00	5.00	14.84
3½ x 4¾	4.20	5.30	15.62
3½ x 5	4.40	5.57	16.40
3¾ x 4¾	4.50	5.67	16.66
3¾ x 5	4.70	5.95	17.50
3¾ x 5¾	5.40	6.80	20.00
4 x 5	5.00	6.33	18.59
4¼ x 5¼	5.55	7.00	20.62
4½ x 5½	6.15	7.63	22.76
4 x 6	6.00	7.52	22.13
4¾ x 5¾	6.70	8.50	25.00
5 x 6	7.30	9.29	27.34

The following discounts are applicable to the above "Base" price to obtain net prices for lots of from 1,000 to 3,000 lin. ft.

Location	Fir	Yellow pine — 75% heart
Pacific coast mills	70%	....
Mississippi mills	....	65%
Chicago warehouse	50%	55%
New York warehouse	40%	45%

On large orders these prices may be bettered by from 10 to 20%.

Prices include boring holes for bolts and pins.

Thus the price of a 6 ft. 6 pin fir cross-arm with a cross-section of 3.25 x 4.25 ins., f. o. b. Chicago Warehouse would be —

$13.12 \times 6 = 79$ cents less 50% = 39.5 cents, net.

And the weight would be $3.4 \times 6 = 20.4$ lbs per cross-arm.

An 8 ft. 8 pin — 3.25 x 4.25 ins. fir cross-arm, f. o. b. New York Warehouse would cost

$13.12 \times 8 = \$1.05$ less 40% = 63 cents, net.

and the weight would be $3.4 \times 8 = 27.2$ lbs. per cross-arm.

Rules for Figuring Prices on Special Sized Arms. Add ¼-in. to depth and width of finished size required to get "rough size." If length required runs into ins., take next higher ft. length. This gives the "rough" size and length of the block from which the arm is made.

Multiply depth by width (rough size) in ins., divide by 12, and multiply by length in ft. This gives number ft. b. m. in block.

Multiply ft. b. m. by 10 to get base price at mill in cts.

To get weight, find ft. b. m. as above, except use actual length required and multiply by 2.7 for fir and 3.4 for yellow pine.

For carbolineating, or immersion for 5 mins. in carbolineum oil, heated to 200 deg. Fahr., add 20% to list prices.

For painting two coats red paint, add 20% to list prices.

For creosoting full vacuum treatment,

12 lbs. per cu. ft., add 50% to list price.

10 lbs. per cu. ft., add 45% to list price.

8 lbs. per cu. ft., add 40% to list price.

For example, to find cost of special size 7 x 6 ins.

$(7 + \frac{1}{4} \times 6 + \frac{1}{4}) = 45.31$ sq. ins.

$10(45.31 \div 12)$ $X =$ base price at mill in cents,

where $X =$ number of feet in length.

Cost of Malleable Iron Feeder Arms. Malleable iron feeder arms have one to six pins complete with bolts and for 3, 4, 4.5, 5, 6, and 7 in. poles cost per lb. of iron from 7 to 10 cts.

Malleable iron triangle, three pin high tension pole arms for high tension light and power wires and having 30 ins. between pins, cost approximately 10 cts. per lb. and weigh 33 lbs. each without pins.

TABLE XLII. CROSS ARM PINS

American Telegraph and Telephone Co., "standard." Steel pin with wood head.

		Price per 100 lbs.	
Size, ins.	Weight per 100 lbs.	Plain	Galv'd.
½ x 4¾	62	$5.00	$7.40
⅝ x 5½	82	5.80	8.50
½ x 1½	57	4.80	7.20
⅝ x 1½	77	5.60	8.00

The above size is the diameter and length of bolt. First two are for wood cross arms. The last are for steel channels or angle iron cross-arms and are without washers.

High Tension Insulator Pins. Malleable iron head and pin on piece with steel bolt with short stud for use on channel and angle iron cross-arm.

		Price per 100	
Size, ins.	Weight per 100, lbs.	Jap'd	Galv'd
4¾	170	$20.80	$26.50
5½	190	21.60	28.00
6	190	22.40	29.00
7½	215	24.00	31.25
9	300	30.00	39.00
10	340	32.00	45.00
18	600	48.00	68.00

The above size is the length of pin plus height of head.

Head diameter is 1 in. for the first four sizes and 1.375 ins. for last three.

WOOD PINS, PAINTED OAK

Size, ins.	Weight, lbs.	Price per 1,000
1¼ x 8	300	$12.50
1½ x 9	400	15.00

The above prices are for lots of less than 250. For lots of 250 to 1,000 a discount of 30% is given and 40% on lots of 1,000 to 2,500 on those given above.

TABLE XLIII. CROSS-ARM BRACES OF PLAIN STEEL

Length, ins.	Weight, lbs. per 1,000	Price per 1,000
	Size of steel, 1 x 3/16 ins.	
20	1,000	$33.75
22	1,100	37.12
	Size of steel, 1 7/32 x 7/32 ins.	
20	1,420	42.48
22	1,560	46.65
24	1,700	50.85
26	1,840	55.10
28	1,980	59.20
30	2,120	63.30
	Size of steel, 1¼ x ¼ ins.	
20	1,670	49.95
22	1,835	54.93
24	2,000	59.85
26	2,165	64.69
28	2,335	69.90
30	2,500	74.80

Guy Clamp. The following are costs of guy clamps.

Matthews Boltless Guy Clamp

Size of guy strand, ins.	Weight, lbs. per 100	Price, each
¼–5/16	50	$0.10
⅜–7/16	130	.15

Prices are on lots of less than 500, 15 to 20% off on 1,000 lots and over.

Galvanized Rolled Steel Guy Clamp

Size, ins.	No. of bolts	Weight, lbs. per 100	Price per 100
3	2	110	$12.00
4	3	150	17.00
6*	3	210	19 50

* A. T. & T. standard.

Prices are on lots of 50 to 100; discount of 9% on lots from 100 to 250 and special prices on lots over 250.

Universal guy clamp, galvanized malleable iron

No. of bolts	Weight, lbs. per 100	Price per 100
2	100	$12.00
3	100	17.50

Prices are on lots of 100 to 300; discount of 9% on lots from 300 to 500 and special prices on lots over 500.

TABLE XLIV. PIN TYPE INSULATORS (WESSELHOEFT)

Material	Operating voltage, volts	Test Voltage Wet volts	Test Voltage Dry volts	Diam, ins.	Height, ins.	No. of parts	Weight, lbs.	Cost
Glass	110–2,200	.....	......	3¼	4	1	1¼	$0.03
Porcelain	13,200	40,000	80,000	6½	3¾	2	3⅜	0.18
Porcelain	22,000	45,000	72,000	7	5	2	5	0.50
Porcelain	33,000	60,000	90,000	9	8	2 or 3	8	0.75
Porcelain	44,000	80,000	110,000	10½	10	3	13	1.20
Porcelain	50,000	95,000	120,000	12	11	3	18	1.50
Porcelain	60,000	115,000	150,000	14	13	4	27	2.00

TABLE XLV. SUSPENSION TYPE INSULATORS (WESSELHOEFT)

Diam. ins.	No. of parts	Spacing, ins.	Test Voltage Wet volts	Test Voltage Dry volts	Ultimate strength, lbs.	Working stress, lbs.	Weight, lbs.	Cost
10	1	5½	50,000	75,000	8,000	4,000	11	$1.00
12	1	6½	50,000	75,000	9,000	4,500	13	1.40
14	2	9	65,000	90,000	12,000	6,000	20	2.00

TABLE XLVI. HIGH VOLTAGE PORCELAIN INSULATORS

Line voltage	Weight, lbs.	Price
6,600	1.0	$0.10
7,500	1.125	.12
8,000	1.2	.13
10,000	1.6	.18
11,000	1.8	.20
13,000	2.3	.26
15,000	2.6	.31
18,000	3.3	.40
20,000	3.8	.46
23,000	4.5	.55
25,000	5.0	.64
27,000	5.5	.70
30,000	6.1	.82
33,000	7.0	.95
36,000	7.8	1.10
40,000	9.0	1.20
45,000	10.5	1.45
50,000	20,0	2.80

TABLE XLVII. WOOD STRAIN INSULATORS WITH GALVANIZED ENDS

Length, ins.	Diameter, ins.	Price per 100
5	1	$21.00
9	1	25.00
12	1	30.00
15	1	32.25
5	1¼	27.35
9	1¼	30.00
12	1¼	35.00
15	1¼	39.35
24	1¼	52.50
36	1¼	65.00
48	1¼	77.50

The average breaking strain for the 1 in. diam. is 2500 lbs. and for 1.25 in. diam. 10,000 lbs.

The above length is the length of wood insulaton and the diam. is that of the wood at the ends. The distance between centers of eyes is 4 to 5 ins. greater than that of the wood insulation.

For insulators having clevis at one end there is an increase of 10% and for those having tapped boss at one end there is an increase of 15% to 20% on the above prices.

TABLE XLVIII. GLASS INSULATORS

	Size, ins.	Weight, lbs. per 1,000	Price per 1,000
Pony	2¼ x 3¼	700	$28.80
Pony double petticoat	2¾ x 3¼	950	33.60
Pony double groove	2 x 3½	760	28.80
Regular insulator	2¾ x 4	1,100	36.00
Std. Western Union double petticoat	3¼ x 4½	1,700	52.80
Long distance pattern	2 7/16 x 3¾	1,000	43.20
Western Union single petticoat	2¾ x 4	1,450	60.00
Deep groove pattern	3 x 4	1,275	52.00
Large double groove	3 x 4¼	1,700	60.00
Deep groove double petticoat	3¼ x 4	1,475	52.80
Extra deep groove double petticoat	3⅛ x 3¾	1,375	52.80

The sizes given are the maximum diam. and heights.

TABLE XLIX. PORCELAIN STRAIN INSULATORS

Size	Dimensions, ins.	Weight per 100 lbs.	Price per 100
1	3¼ x 4¼	162.5	$12.00
2	3⅝ x 5½	275.0	16.00
3	2⅞ x 3½	137.5	10.00
4	2⅜ x 3	87.5	8.00
5	1½ x 2¼	25.0	4.50

Size	Test voltage	Line voltage	Tensile strength	No. pieces per package
1	24,000	8,000	15,000	125
2	21,000	8,000	20,000	100
3	24,000	7,000	15,000	250
4	20,000	5,000	12,000	350
5	telephone work low voltage			1,000

GIANT STRAIN INSULATORS

Diam. of body, ins.	Length	Breaking strength lbs.	Price per 100
1¾	3¾	3,500	$24.85
2	4 7/16	5,000	27.00
2¼	4 13/16	7,000	31.50
2½	6	10,000	42.75

For clevis at one end there will be an increase of $5.50 for the 1.75 and 2 in. sizes and $8.25 increase on 2.25 and 2.5 in. sizes.

For insulators with clevis at both ends, the increase will be twice as much as for one clevis.

The length given above is distance between centers of eyes; there is a slight increase in length in the case of clevis and eye or two clevises.

Comparison of Aluminum and Copper Wire. We have taken the following information from American Handbook for Electrical Engineers: The following table compares the various items for wires having the same length and same resistance and is based on the following assumptions:

	Copper	Aluminum
Per cent. conductivity	98	61
Tensile strength, lbs. per sq. in.	55,000	25,000
Density	8.89	2.70
Price per pound	P	P

COMPARISON OF COPPER AND ALUMINUM WIRES FOR EQUAL RESISTANCES PER UNIT LENGTH

Item	Copper	Aluminum
Cost	1	$0.488 \times \frac{P}{P}$
Cross-section	1	1.63
Diameter	1	1.28
Weight	1	0.488
Breaking strength	1	0.731
Carrying capacity	1	1.13

Disadvantage of Low Tensile Strength. The lower tensile strength of aluminum for equal length and conductance as compared with copper affects the cost of an aerial line in two ways: 1st, by making it necessary to erect the spans with a greater sag or less length in order to reduce the stresses, thereby either increasing the height or the number of poles, and 2nd, by making it necessary to increase the distance between wires on account of the increased sag. The increase in the height of poles for the same spacing amounts to about 10%. (C. L. Johnson.)

Example of Relative Cost. According to the official publications of the Ontario Hydro-Electric Commission on a line consisting of two three-phase circuits, each comprising three 4/0 American wire gage cables, the six cables cost $1,450 per mile as compared with $2,050 per mile for copper cables (copper being at 16 cts. per lb. and aluminum at 23.5 cts. per lb.) showing a saving of nearly 30% on the cables alone. This saving was reduced to 5.6% only on the total cost of the line, partly because the actual towers weighed 1.72 tons against 1.57 tons for towers for an equivalent copper line, and partly because the cost of cables was only 30% of the total cost of the line, including erection but excluding rights-of-way. (C. L. Johnson.) Owing to a tariff of 3.5 cts. per lb. the price of aluminum is higher in the U. S. than in Canada and Europe, so that the saving would have been considerably less at U. S. prices.

Weatherproof Copper Wire. The cost of triple braid wire solid conductor is "Base" * for B. & S. gage sizes 4/0 to 8/0 inclu-

* "Base" cost on copper wire is usually about 1 ct. per lb. higher than the market price of ingot copper or "wire-bar."

sive with an increase of 1 ct. for each size smaller than the No. 8. Double braid wire costs .5 ct. more per lb. than triple braid, as does also triple braid fire and weatherproof and Underwriter's slow burning wires.

Twisted conductors cost about 1 ct. per lb. more than for single conductor.

Stranded conductors cost .25 ct. more than the above, for sizes 1,000,000 circular mils. to No. 2 B. & S. gauge inclusive; .5 ct. more for No. 3; 1 ct. more for Nos. 4 to 6 inclusive; and 1.5 cts. for No. 8; 2 cts. for No. 10 and 5 cts. for No. 12.

Thus with a base price of 16.5 cts. per lb., No. 10 wire, solid conductor, triple braid would cost 17.5 cts.; No. 10 wire, solid conductor, double braid would cost 18 cts. per lb.; if the latter were stranded it would cost 20 cts. per lb. This would make No. 10 wire, solid conductor, triple braid, cost $9.28 per 1000 ft.

In figuring prices of wire it must be remembered that a charge of from $5 to $10 is made for the reels on which the wire is delivered. This amount is rebatable, however, upon the return of the reels in good condition.

Weights of Copper Wire. In Tables L to LV are given the weight per mile of base, double braid weatherproof and triple braid weatherproof wire, both for solid and stranded conductors, and with allowances of 0%, 2.5% and 5% for sag and waste.

TABLE L. WEIGHT PER MILE OF BARE SOLID CONDUCTOR

Size B. & S. gauge	No sag or waste Weight, lbs.	2½% for sag and waste Weight, lbs.	5% for sag and waste Weight, lbs.
0,000	3,382	3,467	3,551
000	2,682	2,749	2,816
00	2,127	2,180	2,233
0	1,687	1,729	1,771
1	1,337	1,370	1,404
2	1,061	1,088	1,114
3	841	862	883
4	667	684	700
6	420	431	441
8	263	270	276
10	166	170	174
12	104	107	109
14	66	68	69

TABLE LI. WEIGHT PER MILE OF BARE CONCENTRIC STRANDED CONDUCTOR

Circ. mils. and B. & S.	No sag or waste Weight in lbs.	2½% sag and waste Weight, lbs.	5% sag and waste Weight, lbs.
2,000,000	32,757	33,576	34,395
1,750,000	28,665	29,382	30,098
1,500,000	24,568	25,182	25,796
1,250,000	20,475	20,987	21,499
1,000,000	16,378	16,787	17,197
750,000	12,276	12,583	12,890
600,000	9,821	10,067	10,312
500,000	8,173	8,377	8,582

Circ. mils. and B. & S.	No sag or waste Weight in lbs.	2½% sag and waste Weight, lbs.	5% sag and waste Weight, lbs.
450,000	7,355	7.539	7,723
400,000	6,536	6,699	6,863
350,000	5,718	5,861	6,004
300,000	4,905	5,028	5,150
250,000	4,087	4,189	4,291
0,000	3,448	3,534	3,620
000	2,729	2,797	2,865
00	2,164	2,218	2,272
0	1,721	1,764	1,807
1	1,361	1,395	1,429
2	1,072	1,099	1,126
3	848	869	890
4	672	689	706
6	423	434	444

TABLE LII. WEIGHT PER MILE OF DOUBLE BRAID WEATHERPROOF SOLID CONDUCTOR

Size B. & S. Gauge	No sag or waste Weight in lbs.	2½% sag and waste Weight, lbs.	5% sag and waste Weight, lbs.
0,000	3,817	3.912	4,008
000	3,098	3,175	3,253
00	2,467	2.529	2,590
0	1,989	2,039	2,088
1	1,553	1,592	1,631
2	1,264	1,296	1,327
3	977	1,001	1,026
4	795	815	835
6	529	542	555
8	349	358	366
10	241	247	253
12	158	162	166
14	107	110	112

TABLE LIII. WEIGHT PER MILE OF DOUBLE BRAID WEATHERPROOF STRANDED CONDUCTOR

Circ. mils. and B. & S. Nos.	No sag or waste Weight, lbs.	2½% sag and waste Weight, lbs.	5% sag and waste Weight, lbs.
2.000.000	35,323	36.206	37,089
1,750.000	31,119	31,897	32,675
1,500,000	26,915	27.588	28,261
1,250.000	22,516	23,079	23,642
1,000.000	18,246	18,702	19,158
750,000	13,913	14,261	14,609
600,000	11,052	11,328	11,605
500,000	9,318	9,551	9,784
450,000	8,452	8,663	8,875
400,000	7,584	7,774	7,963
350,000	6,589	6,754	6,918
300,000	5,721	5,864	6,007
250.000	4,788	4,908	5,027
0,000	3,935	4,033	4,132
000	3,190	3,270	3,350
00	2,544	2,608	2,671
0	2,051	2,102	2,154
1	1,599	1,639	1,679

Circ. mils. and B. & S. Nos.	No sag or waste Weight, lbs.	2½% sag and waste Weight, lbs.	5% sag and waste Weight, lbs.
2	1,301	1,333	1,366
3	1,004	1,029	1,054
4	820	841	861
6	544	558	571

TABLE LIV. WEIGHT PER MILE OF TRIPLE BRAID WEATHERPROOF SOLID CONDUCTOR

Size B. & S. Gauge	No sag or waste Weight, lbs.	2½% sag and waste Weight, lbs.	5% sag and waste Weight, lbs.
0,000	4,050	4,151	4,253
000	3,320	3,403	3,486
00	2,650	2,716	2,783
0	2,150	2,204	2,258
1	1,670	1,712	1,754
2	1,370	1,404	1,439
3	1,050	1,076	1,103
4	865	887	908
6	590	605	620
8	395	405	415
10	280	287	294
12	185	190	194
14	130	133	137
16	105	108	110
18	85	87	89
20	65	67	68

TABLE LV. WEIGHT PER MILE OF TRIPLE BRAID WEATHERPROOF STRANDED CONDUCTOR

Circ. mils. and B. & S. Nos.	No sag or waste Weight, lbs.	2½% sag and waste Weight, lbs.	5% sag and waste Weight, lbs.
2,000,000	37,000	37,925	38,850
1,750,000	32,700	33,518	34,335
1,500,000	28,400	29,110	29,820
1,250,000	23,800	24,395	24,990
1,000,000	19,400	19,885	20,370
750,000	14,900	15,273	15,645
600,000	11,800	12,095	12,390
500,000	10.000	10,250	10,500
450,000	9,100	9,328	9,555
400,000	8,200	8,405	8,610
350,000	7,100	7,276	7,455
300,000	6,200	6,355	6,510
250,000	5,200	5,330	5,460
0,000	4,220	4,326	4,431
000	3,450	3,536	3,623
00	2.760	2,829	2,898
0	2,240	2,296	2,352
1	1,735	1,778	1,822
2	1,425	1,461	1,496
3	1,090	1,117	1,145
4	900	923	945
6	610	625	641

TABLE LVI. COST PER CABLE FOOT OF ERECTING AERIAL CABLE, CHICAGO

Size, pairs	Gauge	Cost of cable	Cost material	Labor	Total
5	22	$0.0489	$0.0133	$0.0400	$0.1022
10	22	.0597	.0133	.0400	.1130
15	22	.0707	.0134	.0353	.1194
20	22	.0812	.0155	.0358	.1325
25	22	.0917	.0166	.0292	.1375
50	22	.1377	.0179	.0331	.1887
100	22	.2374	.0272	.0434	.3080
150	22	.3140	.0278	.0510	.3928
200	22	.4401	.0283	.0540	.5224
15	19	.0900	.0135	.0292	.1327
25	19	.1250	.0181	.0330	.1761
50	19	.2125	.0190	.0421	.2736
100	19	.4926	.0277	.0510	.5713
150	19	.6000	.0281	.0530	.6811
200	19	.7478	.0292	.0560	.8330
5	18	.0700	.0135	.0400	.1235
10	18	.0950	.0135	.0280	.1365
15	18	.1200	.0167	.0290	.1657
20	18	.1400	.0175	.0312	.1887
25	18	.1620	.0184	.0405	.2209
50	18	.4250	.0277	.0501	.5028
100	18	.6450	.0297	.0530	.7277

Supervision and other overhead costs not included. Labor costs on small sized cables are high because they involve short lengths.

TABLE LVII. WEIGHT AND COST OF STANDARD PLAIN GALVANIZED STEEL STRAND CONDUCTORS

(For guys, signal strand, trolley line span wire and other purposes. Composed of 7 wires twisted together)

Diameter, ins.	Wt. per 1,000 ft., lbs.	Approx. breaking strain, lbs.	Price per 100 ft.
½	510	8,500	$2.20
7/16	415	6,500	1.80
⅜	295	5,000	1.40
5/16	210	3,800	0.90
¼	125	2,300	0.70
7/32	95	1,800	0.60
3/16	75	1,400	0.50
5/32	55	900	0.46
⅛	32	500	0.40
3/32	20	400	0.32

The prices given are for single galvanized and are approximately average for lengths of from 1,000 to 2,500 ft.; with large orders more favorable prices can be obtained under normal conditions. For double galvanized wire the prices will be about 10% more than those given.

The weight of Siemens-Martin strand is approximately the same as for the standard galvanized strand. Prices given are for orders of from 1,000 to 3,000 ft.

The following notes on the uses of "Strand" wires are taken from the 1915 Year Book of the Western Electric Company.

Guy Strand. Extra galvanized Siemens-Martin strand is fre-

TABLE LVIII. COST AND STRENGTH OF EXTRA GALVANIZED SIEMENS-MARTIN STRAND CONDUCTORS

Diameter, ins.	Tensile strength lbs.	Net price per 100 ft.
5/8	19,000	$3.90
1/2	11,000	2.50
7/16	9,000	2.05
3/8	6,800	1.60
5/16	4,860	1.30
9/32	4,380	1.00
1/4	3,050	0.90
3/16	2,000	0.75
1/8	900	0.50

quently employed to guy electric railway, telegraph and telephone poles.

Messenger Strand. For .3125 in. diam. extra galvanized Siemens-Martin strand, .375 in. or .4375 in. diam. extra galvanized high strength strand is stretched from pole to pole, and from this messenger strand, so called, the heavy lead-encased telephone cable is suspended by means of clips, wire or cord at short intervals. A messenger strand thus sustains the stress due to weight of cable, wind or ice load. Common galvanized strand should never be used for this purpose, as it does not possess the requisite strength.

Catenary Method of Supporting Trolley Wires. One or more messenger strands are stretched from the center of the tracks. Every few feet along this messenger strand are pendent hangers that clamp on to the trolley wire, detaining it in a rigid, straight, horizontal line. For a single messenger strand carrying 4/0 copper trolley wire, in spans of 125 to 150 ft., .375-in. or 7/16-in. diam., extra galvanized Siemens-Martin strand is frequently used. For longer spans, up to 225 ft. the .376-in. or .4375-in. extra galvanized high strength strand is preferable.

Lightning Arrester for Transmission Lines. To protect high-tension current transmission lines from destructive lightning a .375-in. diam. extra galvanized Siemens-Martin strand, known as an "overhead ground strand," is strung at the highest point on the supporting towers, this "overhead ground strand" being connected at frequent intervals with the ground. The extra galvanized Siemens-Martin strand, because of its great conductivity, is employed almost exclusively for the "overhead ground strand."

CHAPTER XII

UNDERGROUND ELECTRICAL TRANSMISSION AND DISTRIBUTION

Many of the data which follow have been abstracted from Clarence Mayer's Telephone Construction — Methods and Cost, and the reader who desires a much more detailed analysis of this subject than can be given here, is referred to Mr. Mayer's book.

For very complete detail costs of concrete, of paving and removing pavements, and of trench excavating, see Gillette's Handbook of Cost Data.

Underground Conduit. The following labor costs of constructing conduit are from Mayer's Telephone Construction. McRoy tile, cement, vault frames and cover, creosoted plank and pump log were shipped in cars and unloaded and distributed by the conduit gang. All other material was bought delivered on the job.

The method of installing McRoy tile, Class "A" construction, shall be as follows: The trench shall first be prepared with a foundation of 3 ins. of concrete, leveled and tamped. Upon this the tile shall be laid. Insert the necessary dowel pins and place the next tile in line, centering the tile by means of the dowel pins. Cover the top and sides of each joint with a strip of burlap 6 ins. wide to prevent the entrance of concrete into the duct.

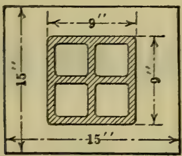
The successive length of tile shall then be laid in similar manner. When two or more sections are laid side by side all joints shall be staggered. In joining 2, 3 or 6-duct sections at least one dowel pin shall be used, or if the duct is designed for more than one, two shall be used. When the tile is laid it is enclosed at the sides and top with a wall of concrete 3 ins. thick and well tamped.

If the conduit has a large cross section it will be built up in tiers. When the first tier is laid and lined up the sides of the trench shall be filled in with well tamped concrete to a thickness of 3 ins. and to a height flush with the top of the tile. The upper tiers shall then be laid successively, one upon the other, in a manner similar to the first tier. The complete section shall be covered with 3 ins. of well-tamped concrete, after which the trench shall be refilled. In dumping concrete into the trench and in laying tile care should be taken not to knock off earth into the trench. Any dirt falling onto the work shall be carefully removed before proceeding with the construction.

In refilling the trench the better part of the material excavated shall be used. It must be well tamped into place and the trench covered with a crown of 3 or 4 ins. If the street is paved, all

surplus must be gathered up and carried away, and the displaced paving material shall be replaced temporarily. After conduit runs are completed all ducts shall be closed with wooden plugs.

Concrete may be mixed by hand or by machine. If mixed by hand it shall be done on a timber platform to prevent waste of water and material, except where the following pavements are encountered: (1) asphalt; (2) brick; (3) macadam; (4) creosoted wood block. When mixing concrete on any of these pavements the street shall be swept clean for a place sufficient to allow for mixing the concrete. The stone or gravel shall first be placed in a layer about 4 ins. thick; sand or screenings added and spread out evenly, and the cement added and evenly distributed. The dry mixture shall be turned over by shovels at least three times so that it is thoroughly mixed. Sufficient water shall be used so that when placed in a wheel-barrow the concrete shall be very moist and in a semi-fluid condition. All concrete shall be free from dirt or any foreign material. Concrete shall be used within 2 hours of the time it is mixed.



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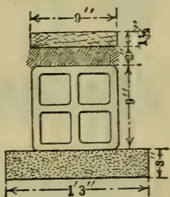

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Fig. 1. McRoy tile, 4-duct conduit, class "A" construction.
Fig. 2. McRoy tile, 4-duct conduit, class "B" construction.

The proportions of materials to be used in mixing concrete for conduit construction shall be as follows: If crushed stone concrete is used, 1 part of American Portland cement, 4 parts ¼-in. screenings and 8 parts No. 3 (¾-in.) stone. If gravel concrete is used, 1 part American Portland cement, 4 parts sand and 8 parts gravel; 1 bag of cement shall be considered 1 cu. ft.

The method of installing class "B" construction shall be the same as described for class "A," except in the following particulars:

The tile shall be laid on a 3-in. bed of concrete. Upon the top of the tile there shall be placed 2 ins. of earth, which shall be free from large stone. Upon this layer of earth a 1.5-in. creosoted plank shall be laid of the same width as the conduit formation. The tile joints shall be closed by means of strips of burlap which shall be placed around the tile so as to cover the top and sides. The burlap shall be saturated with a thin, neat cement mortar, and shall be plastered on the sides and top with ½-in. of cement mortar mixed in the proportion of 1-2. The burlap shall be 6 ins. wide and of sufficient length to overlap the width of the tile.

TABLE I. AVERAGE COST OF McROY CONDUIT CONSTRUCTION IN CITIES

No. ducts	Class	Kind of soil	Cost of teaming per lin. ft.	Cost of excavating per lin. ft.	Cost of handling and mixing concrete and dumping into trench per lin. ft.	Cost of laying tile plank and concrete per lin. ft.	Cost of filling in per lin. ft.	Supervision per lin. ft.	Total cost per lin. ft.	Total cost per duct ft.
2	A	Clay	$0.0267	$0.0629	$0.0297	$0.0131	$0.0440	$0.0310	$0.2074	$0.1037
		Hard clay.	.0438	.0705	.0386	.0133	.0540	.0432	.2634	.1317
		Av.	.0352	.0667	.0342	.0132	.0490	.0371	.2354	.1177
3	A	Sand	.0160	.0588	.0441	.0294	.0147	.0515	.2145	.0715
		Clay	.0174	.0663	.0536	.0169	.0503	.0367	.2412	.0804
		Hard clay.	.0223	.0770	.0425	.0125	.0415	.0314	.2272	.0757
		Av.	.0186	.0674	.0467	.0196	.0355	.0398	.2276	.0759
3	B	Sand	.0167	.0593	.0172	.0178	.0254	.0380	.1744	.0581
		Clay ..... and Hard clay.	.0163	.0652	.0189	.0192	.0492	.0406	.2094	.0698
		Hard clay.	.0198	.0781	.0166	.0199	.0521	.0372	.2237	.0746
		Av.	.0176	.0675	.0176	.0190	.0422	.0386	.2025	.0675
4	A	Sand	.0298	.0904	.0529	.0296	.0201	.0426	.2654	.0664
		Clay ..... and	.0381	.1291	.0490	.0322	.0384	.0447	.3315	.0829
		Hard clay.	.0259	.1547	.0560	.0330	.0602	.0671	.3969	.0992
		Av.	.0313	.1247	.0526	.0316	.0396	.0515	.3313	.0828
4	B	Sand	.0253	.0917	.0294	.0190	.0350	.0382	.2386	.0597
		Clay ..... and	.0276	.1194	.0282	.0201	.0521	.0416	.2890	.0722
		Hard clay.	.0301	.1601	.0201	.0242	.0572	.0574	.3491	.0873
		Av.	.0277	.1237	.0259	.0211	.0481	.0457	.2922	.0731
5	A	Sand	.0300	.1121	.0649	.0342	.0501	.0417	.3330	.0666
		Clay	.0291	.1507	.0620	.0387	.0604	.0481	.3890	.0778
		Av.	.0296	.1314	.0635	.0364	.0552	.0449	.3610	.0722

TABLE I — (*Continued*)

6	A	Sand	.0234	.0911	.0614	.0428	.0514	.0591	.3292	.0549
		Clay	.0301	.1348	.0603	.0212	.0820	.0713	.3997	.0666
		and Hard clay.	.0397	.1602	.0533	.0330	.0834	.0698	.4394	.0732
		Av.	.0311	.1287	.0583	.0323	.0723	.0667	.3894	.0649
6	B	Sand	.0315	.1127	.0227	.0343	.0576	.0601	.3189	.0532
		Clay	.0296	.1483	.0259	.0360	.0801	.0662	.3861	.0643
		and Hard clay.	.0380	.1587	.0204	.0313	.0740	.0742	.3966	.0661
		Av.	.0330	.1399	.0230	.0339	.0706	.0668	.3672	.0612
7	A	Clay	.0307	.1429	.0693	.0341	0701	.0768	.4239	.0606
8	A	Sand	.0246	.1196	.0686	.0302	.0717	.0612	.3759	.0470
		Clay	.0384	.1547	.0702	.0366	.0642	.0708	.4349	.0544
		and Hard clay.	.0401	.1704	.0603	.0327	.0823	.0796	.4654	.0582
		Av.	.0344	.1482	.0664	.0332	.0727	.0705	.4254	.0532
9	A	Sand	.0311	.1257	.0743	.0287	.0733	.0711	.4042	.0449
		Clay	.0299	.1605	.0728	.0402	.0839	.0805	.4678	.0520
		and Hard clay.	.0471	.1782	.0696	.0423	.0876	.0670	.4921	.0547
		Av.	.0360	.1548	.0722	.0371	.0816	.0730	.4547	.0505
11	A	Sand	.0402	.1464	.0884	.0493	.0812	.0804	.4859	.0442
		Clay	.0501	.1848	.0779	.0501	.0934	.0902	.5465	.0497
		Av.	.0452	.1656	.0831	.0497	.0873	.0853	.5162	.0469
12	A	Sand	.0422	.1457	.0787	.0522	.0786	.0781	.4755	.0396
		Clay	.0517	.1911	.0824	.0498	.0948	.0829	.5527	.0461
		and Hard clay.	.0476	.2127	.0760	.0517	.1014	.0887	.5781	.0482
		Av.	.0472	.1832	.0790	.0512	.0916	.0832	.5354	.0446

TABLE IA. QUANTITIES AND COST OF MATERIAL AND LABOR REQUIRED IN MC ROY TILE CONDUIT CONSTRUCTION

Conduit cross section, ducts	8	6	6	4	4	3	3	2
Class	A	A	B	A	B	A	B	A
Bags cement at .4325	.1578	.1327	.0456	.1147	.0360	.1147	.0456	.0955
Yds. sand at 1.90	.0236	.0198	.0068	.0171	.0054	.0171	.0068	.0143
Yds. gravel at 1.90	.0471	.0397	.0136	.0343	.0107	.0343	.0136	.0285
Total yd. cement, sand and gravel	.0764	.0642	.0221	.0555	.0174	.0555	.0221	.0462
Yds. concrete	.0509	.0427	.0147	.0370	.0116	.0370	.0147	.0308
Cost concrete at $3.98	$.2026	$.1704	$.0585	$.1463	$.0462	$.1463	$.0585	$.1226
No. dowel pins per duct	3	2	2	1	1	2	2	1
Cost dowel pins at .00325	.00325	.00217	.00217	.00109	.00109	.00325	.00325	.00163
Inches burlap 6⅔ in. wide, per duct	66	37	37	33	33	29	29	25
Cost of burlap at .014	$.0086	$.0048	$.0048	$.0043	$.0043	$.0057	$.0057	$.0049
Cost of duct at .0396	.3168	.2376	.2376	.1584	.1584	.1188	.1188	.0792
No. inches 1½ x 9 creosote plank	....	....	13½	....	13½	....	19½	....
Cost creosote plank	....	....	.0597	....	.0597	....	.0862	....
Total cost material, not including waste, etc.:								
Per lineal ft.	.5313	.4150	.3628	.3101	.2687	.2741	.2724	.2083
Per duct ft.	.0664	.0692	.0605	.0775	.0672	.0914	.0908	.1041
Duct and cement	.0268	.0180	.0160	.0134	.0116	.0116	.0100	.0092
Cost unloading and distributing creosote plank......								
Per lineal ft.	....	....	.0051	....	.0029	....	.0051	....
Total cost unloading and distributing material per	.0268	.0180	.0211	.0134	.0145	.0116	.0151	.0092
duct ft.	.0034	.0030	.0035	.0034	.0036	.0039	.0050	.0046
Labor cost:								
Excavating	.0344	.0311	.0330	.0313	.0277	.0186	.0176	.0352
Teaming	.1482	.1287	.1399	.1247	.1237	.0674	.0675	.0667
Mixing, handling, dumping concrete	.0664	.0583	.0230	.0526	.0259	.0467	.0176	.0342
Laying tile and plank	.0332	.0323	.0339	.0316	.0211	.0190	.0190	.0132
Filling in	.0727	.0723	.0706	.0396	.0481	.0355	.0422	.0490
Supervision and expense	.0705	.0667	.0668	.0515	.0457	.0398	.0386	.0371
Labor cost per lineal ft.	$.4254	$.3894	$.3672	$.3313	$.2922	$.2276	$.2025	$.2354
Labor cost per duct ft.	.0532	.0649	.0612	.0828	.0731	.0759	.0675	.1177
Total cost per lineal ft.	.9835	.8224	.7511	.6548	.5754	.5133	.4900	.4529
Total cost per duct ft.	.1230	.1311	.1252	.1637	.1439	.1712	.1633	.2264

The rates of wages on which the data given in Tables I–V are based are as follows:

	Per day of 9 hrs.
Foreman	$3.50 to $4.00
Assistant foreman	2.50 to 3.00
Timekeeper	2.00 to 2.50
Watchman	2.00
Waterboy	1.00
Laborers	2.00
Teams	5.00
	Per hr.
Bricklayers	$0.65 to $0.75

The regular hourly rate was paid for overtime. These tables comprise data on the labor cost of constructing over 250,000 ft. of conduit and lateral.

McRoy tile, used in building main conduits, is made of vitrified clay in 1, 2, 3, 4 and 6-duct sizes. The 1, 2 and 3-duct are 2 ft. long and the 4 and 6-duct 6 ft. long. The approximate weight is 8½ lbs. per duct foot.

Methods of Laying. Mayer says that two 4-ducts are laid with greater facility, form a more stable construction and cost less for material and labor than a 6-duct and a 2-duct formation, and in deciding whether to lay two 4-ducts side by side or one on top of the other, the preference should be given to the former, because work is easier in a wide trench; and, as a rule, it is cheaper to dig wide than deep even if the street is paved — repairing contractors charge for a yard although the trench may be 15 ins. wide.

Underground Toll Conduit. The following data from Mayer's Telephone Construction give the costs of one of the largest multiple duct conduits ever installed. It comprises 824,862 duct feet of conduit and 318 vaults. In securing these data special attention was paid to accuracy and uniformity. A competent cost man was assigned to each gang, and in some cases, where gangs were large, two men were engaged in keeping costs. Reports were made daily to the cost statistician who had an office on the ground and who personally supervised the taking of the costs. The work was divided into three divisions, each division being subdivided into two or three sections with a separate gang for each section. The work commenced in June, and with the exception of a small part, delayed on account of right of way trouble, was completed by November 1st.

Table III is a summary of the entire work, showing in detail average costs of each of the three divisions of the job. The unloading and distributing cost on Divisions 1 and 3 were higher than Division 2 on account of having been further away from the freight depot. The freight on material for Division 1 was high on account of being further away from the shipping point than either Divisions 2 or 3, and also on account of the quantity of creosote plank used, on which freight rates are high. The supervision, traveling and livery under the heading of expense were incurred by right of way men, superintendent of construction and assistant superintendents.

TABLE III. COST OF TOLL CONDUIT (MC ROY TILE)

(Divisions 1, 2 and 3.)

Cost of Constructing Conduit and Vaults

Division number	Average cross section	No. of lin. trench ft.	No. of duct ft. laid	Cost of teaming per lin. ft. $	Cost of teaming per duct ft. $	Cost of excavating per lin. ft. $	Cost of excavating per duct ft. $	Cost of handling, mixing and dumping concrete per lin. ft. $	Cost of handling, mixing and dumping concrete per duct ft. $
1	3.31	76,262	252,759	.0200	.0061	.0747	.0226	.0190	.0057
2	6.77	53,372½	361,271	.0449	.0066	.1543	.0228	.0448	.0066
3	4.78	44,104	210,832	.0233	.0049	.1478	.0309	.0332	.0069
Total ..	4.75	173,738½	824,862	.0285	.0060	.1177	.0248	.0305	.0064

Division number	Cost of laying tile concrete and plank per lin. ft. $	Cost of laying tile concrete and plank per duct ft. $	Cost of filling in per lin. ft. $	Cost of filling in per duct ft. $	Total cost of duct per lin. ft. $	Total cost of duct per duct ft. $	Cost of vaults per lin. ft. $	Cost of vaults per duct ft. $	Cost of vaults and trench per lin. ft. $	Cost of vaults and trench per duct ft. $
1	.0175	.0053	.0340	0102	.1652	.0499	.0490	.0147	.2142	.0646
2	.0411	.0061	.0774	.0114	.3625	.0535	0685	.0102	.4310	.0637
3	.0309	.0065	.0435	.0091	.2787	.0583	.0574	.0120	.3361	.0703
Total ..	.0282	.0059	.0497	.0105	.2546	.0536	.0571	.0120	.3117	.0656

Placing Material on Job

Division number	Unloading and distributing material per lin. ft.	Unloading and distributing material per duct ft.	Freight per lin. ft.	Freight per duct ft.	Total cost of placing on job per lin. ft.	Total cost of placing on job per duct ft.
1	$.0277	$.0084	$.0152	$.0046	$.0429	$.0130
2	.0271	.0040	.0139	.0021	.0410	.0061
3	.0499	.0105	.0073	.0015	.0572	.0120
Total	.0332	.0070	.0128	.0027	.0460	.0097

Expense

Division number	Repaving per lin. ft.	Repaving per duct ft.	Right of way supervision, traveling, livery, incidental per lin. ft.	Right of way supervision, traveling, livery, incidental per duct ft.	Total expense per lin. ft.	Total expense per duct ft.
1	$.0013	$.0004	$.0378	$.0114	$.0391	$.0118
2	.0005	.0001	.0600	.0088	.0605	.0089
3	....	....	.0396	.0083	.0396	.0083
Total	.0007	.0002	.0451	.0095	.0458	.0097

Division number	Total labor and expense per lin. ft.	Total labor and expense per duct ft.	Material per lin. ft.	Material per duct ft.	Total cost per lin. ft.	Total cost per duct ft.
1	$.2962	$.0893	$.4735	$.1429	$.7697	$.2322
2	.5325	.0787	.5082	.0750	1.0407	.1537
3	.4329	.0906	.4878	.1020	.9207	.1926
Total	.4035	.0850	.4878	.1027	.8913	.1877

Pump Log Conduit. Mayer in Telephone Construction says creosoted pump log is used in building conduit where the soil is very wet and frequent excavations liable. It is made of yellow or Norway pine, creosoted. The section is 4.5 ins. square, with a 3-in. bore. Each log is provided with mortise and tenon. Its length is 2 ft. to 8 ft.

The trench for pump log shall be excavated in the same manner as described for McRoy tile conduit construction. Pump log shall be laid directly upon the bottom of the trench. Where two or more ducts are used they shall be laid so as to break joints. When the pump log is laid and well settled in position, a creosoted plank 1½ ins. thick and of the width of the conduit shall be laid on top of the ducts. There shall then be driven one on either side, 3 in. x 1.5 in. x 3 ft. creosoted stakes. The stakes shall be sharpened to a point and driven at intervals of 6 ft. with a 3-in. face parallel to the line of the conduit. The tops of the stakes shall be fastened together

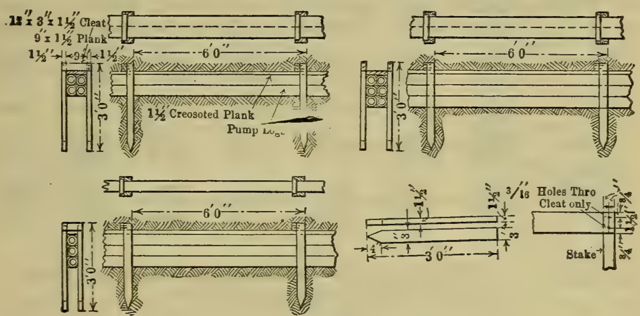


Fig. 3. Method of laying pump log.

by a cleat, of the same size as the stakes, cut to length and drilled for two 3½-in. wire nails. The trench shall then be refilled. The method of laying pump log is shown by Fig. 3.

Lateral Conduit. Mayer's Telephone Construction says lateral conduit, sometimes called subsidiary conduit, is so named from the direction in which it runs to the main conduit. Laterals are built to carry subsidiary cable under ground to a building or pole.

Sewer tile is used in lateral construction because it serves the purpose better than either McRoy tile or pump log and because it is cheapest to install. Whereas the McRoy tile requires a foundation in order to keep its alignment — dowel pins not entirely serving this purpose — and both pump log and McRoy tile require a trench that has a level bottom and is wide enough to permit foot room; sewer tile requires no concrete foundation, as the bell joints when cemented hold the alignment sufficiently well for lateral construction, it may be laid in a trench that is excavated in a V-shape, thereby saving time in excavating. The bottom of the trench may

be very uneven as the bell ends of sewer tile bridge the parts between joints, and the only requirements in laying are that the end of one tile shall fit into the bell end of another. This may readily be done by scraping away any excess earth with a stick of wood. On account of the usual small diameter of lateral cable the lateral conduit may be installed without special regard to alignment, except when the lateral is very long; whereas if McRoy tile is laid

TABLE IV. AVERAGE COST OF PUMP LOG CONDUIT CONSTRUCTION IN CITIES

No. ducts		Teaming	Excavating	Laying	Filling in	Supervision	Total per lin. ft.	Total per duct ft.
1	Sand and water	$0.0304	$0.0612	$0.0177	$0.0314	$0.0240	$0.1647	$0.1647
	Clay ...	0.0281	0.0574	0.0189	0.0247	0.0262	0.1553	0.1553
	Clay and water	.0331	.0818	.0213	.0386	.0341	.2089	.2089
	Av.	.0305	.0668	.0193	.0316	.0281	.1763	.1763
2	Sand and water	.0334	.0843	.0278	.0397	.0299	.2151	.1076
	Clay and water	.0317	.1054	.0262	.0411	.0352	.2396	.1198
	Av.	.0325	.0949	.0270	.0404	.0326	.2274	.1137
4	Sand and water	.0412	.1401	.0411	.0519	.0496	.3239	.0810
	Clay ...	.0487	.1482	.0490	.0537	.0512	.3508	.0877
	Av.	.0449	.1442	.0451	.0528	.0504	.3374	.0844

TABLE V. AVERAGE COST OF SEWER TILE LATERAL CONSTRUCTION IN CITIES

No. ducts	Kind of soil	Teaming	Excavating	Laying tile, plank and concrete	Filling in	Supervision	Total cost per lin. ft.	Total cost per duct ft.
1	Sand ...	$0.0099	$0.0364	$0.0201	$0.0219	$0.0291	$0.1174	$0.1174
1	Clay ...	.0167	.0467	.0156	.0260	.0327	.1377	.1377
1	Hard clay...	.0234	.0581	.0198	.0293	.0302	.1608	.1608
1	Very hard clay...	.0408	.0720	.0178	.0311	.0414	.2031	.2031
1	Av.	.0227	.0533	.0183	.0271	.0333	.1547	.1547
2	Clay ...	.0201	.0709	.0223	.0502	.0390	.2025	.1013

without care being used in alignment the armor of the cable would probably be cut or caught on the ends of the ducts when pulling in the cable.

Underground Construction. The following is abstracted from an article by L. W. Moxey, Jr., in Electrical World, Dec. 18, 1915.

The first item to be considered in underground construction is the cost of excavating, which should be figured per cubic yard.

Every contractor should know what these costs are under various conditions, such as a sand or clay soil, rotten or solid rock, etc. The average laborer is capable of excavating about 180 cu. ft. of clay soil per ten-hour day.

Brief specifications follow: Laterals when laid in the main trench, or in a separate trench, shall be single duct, 3-in. sewer tile. Connections between lateral laid in the main trench and lateral laid in a separate trench shall be made with standard bends of sewer tile. Where lateral is laid in the main conduit trench it shall be located at the top of the conduit formation and shall be included in the enclosing concrete.

Where lateral is laid in separate trench the trench shall be wide enough to permit convenient laying and of sufficient depth to make the completed lateral with its protecting plank at least 18 ins. below the grade of the street. Joints of lateral shall be well protected with cement mortar or concrete. Over the lateral, when laid in separate trench, shall be placed about 3 ins. of earth, which shall be free from large stones. This earth shall be well tamped, and on top of this shall be placed a creosoted plank, 1.5 ins. x 9 ins., to prevent injury in subsequent excavations.

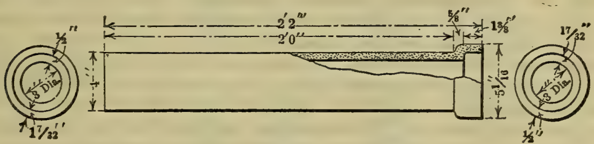


Fig. 4.

The dimensions are usually as follows: inside diam. 3 ins.; shell 0.5 in.: length 2 ft.

Manholes must also be taken into consideration. If the manholes are to be brick-lined, the cost will vary from 40 cents to $1 per cubic foot of brickwork. Such miscellaneous items as the cost of labor for manhole drains, etc., must be figured for each job, since it seems impossible to obtain any fair average of costs on these items.

Only average figures for labor cost are given, and the range of variation in many cases will be found to be greater than that presented in the table.

TABLE VI. OUTSIDE DIMENSIONS OF VITRIFIED DUCTS

Type	Bore, round or square	Outside dimensions, ins.
Single-way	3½-ins.	5 by 5 by 18
Two-way	3½-ins.	4 by 9 by 24
Three-way	3½-ins.	5 by 13 by 24
Four-way	3½-ins.	9 by 9 by 24
Six-way	3½-ins.	9 by 13 by 36
Nine-way	3½-ins.	13 by 13 by 36
Nine-way	2 -ins.	9 by 9 by 36

TABLE VII. LABOR COSTS PER FOOT FOR LAYING DUCTS

Item	Cost
Laying duct and cementing joint:	
Single-way	\$0.03 –\$0.06
Two-way	0.05 – 0.10
Three-way	0.08 – 0.16
Four-way	0.10 – 0.20
Six-way	0.14 – 0.28
Nine-way	0.20 – 0.40
Laying conduit or pipe:	
½-in. conduit	\$0.03 –\$0.05
¾-in. conduit	0.04 – 0.06
1 -in. conduit	0.05 – 0.07
1¼-in. conduit	0.06 – 0.08
1½-in. conduit	0.065– 0.09
2 -in. conduit	0.07 – 0.10
2½-in. conduit	0.075– 0.11
2½-in. conduit	0.08 – 0.12
3 -in. conduit	0.09 – 0.14
4 -in. conduit	0.12 – 0.18

Cost of Transmission Conduit Installed. The following data, presented in the Boston Edison street-lighting case by the company for the consideration of the Massachusetts Gas and Electric Light Commission, were published in Electrical World March 31, 1917.

In the compilation, Table VIII, the significant data are the types of construction and the unit costs, which are given in the first and last columns. In presenting the data to the commission the unit costs given, which are the result of the company's extended experience, were applied to the quantities in the second and third columns, and later the prorated cost of conduit for street-lighting service only was deduced. The quantities are printed in connection with the unit costs in the third column to show the relative importance of the various types of duct construction for underground transmission work in Boston proper. The prices include engineering, incidentals and contractor's profit.

Fiber Duct, Advantages and Materials Required for Installing. The following has been abstracted from an article in Electrical World, March 10, 1917. Fiber duct consists of wet wood pulp or fiber which is wrapped about a mandrel in a thin film while under pressure. When built up to the proper thickness it is dried and then saturated with a bituminous compound. The conduit is manufactured with four general types of joints, the use and nature of which is implied in the name. These are the socket, the drive, the screw and the sleeve. The socket type is generally used with the concrete envelope, while the other types have no form of protection, being laid directly in the earth.

The advantage of light weight stands out primarily for fiber duct, and due to this the freight and cartage rates per foot are much lower than for other types of materials. Approximately three times as many duct feet of fiber duct may be carried in the same car as of tile duct. Likewise in handling the duct, one man can carry

TABLE VIII. COST OF INSTALLING DIFFERENT KINDS OF DUCT

Under the heading "Material," F. stands for fiber, V.C. for vitrified clay, C-L.I.P. for cement-lined iron pipe, and I. for iron.

	Ducts per conduit	Diameter of ducts (ins.)	Material	Conduit feet	Duct feet	Average cost per duct ft. (cts.)
Under dirt sidewalk	6	3½	F.	9312.0	55,872.0	45
Under dirt.....	8	3½	F.	4502.1	36,016.8	30
	10	3½	F.	16.3	163.0	30
	12	3½	F.	402.2	4,826.4	30
	16	3⅜	V.C.	58.5	936.0	25
Under granite blocks with cement grout and concrete base.	8	3	C.-L.I.P.	1705.8	13,646.4	60
	12	3	C.-L.I.P.	25.0	300.0	45
	20	3	C.-L.I.P.	245.0	4,900.0	35
	30	3⅜	V.C.	584.0	17,520.0	30
Under wooden blocks with concrete base.	4	3	C.-L.I.P.	1319.6	5,278.4	80
	6	3⅜	V.C.	141.7	850.2	75
	8	3½	F.	7702.3	61,618.4	60
	12	3½	F.	953.5	11,342.0	45
	14	3⅜	V.C.	929.1	13,004.6	40
	24	3⅜	V.C.	802.9	19,269.6	30
Under bitulithic cement	4	3	C.-L.I.P.	1365.3	5,461.2	80
	6	3⅜	V.C.	1467.3	8,803.8	75
	8	3⅜	V.C.	1467.3	8,803.8	75
	8	3⅜	V.C.	90.6	724.8	60
	9	3⅜	V.C.	3899.0	35,091.0	45
	10	3	C.-L.I.P.	400.1	4,001.0	45
	12	3½	F.	171.8	2.061.6	45
	12	3⅜	V.C.	153.1	1,837.2	45
	15	3⅜	V.C.	280.7	4,210.5	40
	18	3⅜	V.C.	77.3	1,391.4	35
Under macadam	2	3⅜	V.C.	319.9	639.8	60
	4	3½	F.	394.5	1,578.0	50
	4	3	C.-L.I.P.	829.1	3,316.4	50
	4	3⅜	V.C.	160.0	640.0	50
	6	3½	F.	8812.2	52.909.2	45
	8	3⅜	V.C.	3579.1	30,632.8	30
	8	3½	F.	9634.0	77,072.0	30
	10	3½	F.	3306.6	33,066.0	30
	12	3½	F.	8171.9	98,062.2	30
	12	3	C.-L.I.P.	846.8	10,161.6	30
	12	3⅜	V.C.	56.7	680.4	30
	14	3½	F.	2096.9	29,356.6	25
	14	3⅜	F.	182.1	2,549.4	25
	16	3½	F.	727.4	11,638.4	25
	20	3⅜	V.C.	9.1	182.0	25
	24	3½	F.	239.8	5,755.2	25
	30	3½	V.C.	196.4	5,892.0	25
	67	3⅜	V.C.	6.0	402.0	25
Under asphalt..	6	3⅜	V.C.	28.0	168.0	75
	6	3½	F.	330.2	1,981.2	75
	7	3½	F.	87.5	612.5	60
	8	3½	F.	230.5	1.844.0	60
	10	3½	F.	1534.2	15,342.0	45
	12	3⅜	V.C.	591.7	7,100.4	45
	15	3⅜	V.C.	11.2	168.0	40
	18	3½	F.	14.4	259.2	35

	Ducts per conduit	Diameter of ducts (ins.)	Material	Conduit feet	Duct feet	Average cost per duct ft. (cts.)
	30	3⅜	V.C.	126.0	3,780.0	30
	32	3⅜	V.C.	16.0	512.0	30
Under granite blocks	3	3	C.-L.I.P.	68.4	205.2	50
	4	3½	F.	10.3	41.2	50
	4	3⅜	V.C.	1509.7	6,038.8	50
	6	3	C.-L.I.P.	715.3	4,291.8	45
	6	3½	F.	270.3	1,621.8	45
	8	3⅜	V.C.	7212.2	57,697.6	30
	8	3	C.-L.I.P.	7059.4	56,475.2	30
	9	3⅜	V.C.	2417.2	21,754.8	30
	10	3	C.-L.I.P.	71.5	715.0	30
	10	3½	F.	1396.4	13,964.0	30
	12	3⅜	V.C.	2189.5	26,274.0	30
	12	3	C.-L.I.P.	7882.7	94,592.4	30
	12	3½	F.	4904.8	58,857.6	30
	12	3½	F.	4904.8	58,857.6	30
	14	3⅜	V.C.	20.3	284.2	25
	15	3⅜	V.C.	6753.7	101,305.5	25
	15	3½	F.	154.1	2,311.5	25
	18	3⅜	V.C.	193.5	3,483.0	25
	18	3½	F.	344.5	6,201.0	25
	24	3	C.-L.I.P.	249.3	5,983.2	25
	24	3½	F.	223.5	5,364.0	25
	30	3⅜	V.C.	586.4	17,592.0	25
Under granite blocks with pitch-joints and concrete base	4	3	C.-L.I.P.	4960.3	19,841.2	80
	6	3	I.	19.6	117.6	75
	6	3⅜	V.C.	216.6	1,299.6	75
	6	3⅜	V.C.	216.6	1,299.6	75
	8	3	I.	147.6	1,180.8	65
	8	3⅜	V.C.	1092.8	8,742.4	65
	8	3	C.-L.I.P.	9673.9	77,391.2	65
	10	3½	F.	8089.8	80,898.0	45
	11	3	C.-L.I.P.	120.7	1,327.7	45
	12	3½	F.	346.6	4,159.2	45
	12	3⅜	V.C.	5165.8	61,989.6	45
	18	3	C.-L.I.P.	208.1	3,745.8	35
	24	3	C.-L.I.P.	205.0	4,920.0	30
	30	3	C.-L.I.P.	101.4	3,042.0	.30
	30	3⅜	V.C.	237.0	7,110.0	30

several lengths of fiber duct aggregating many lineal feet as opposed to one section of multiple tile duct. In installing the duct one man can remain in the trench and another hands him the duct, while with other materials it usually takes more than one man to handle the material at the top of the trench.

The breakage and waste is almost negligible with fiber duct, a distinct advantage being that broken pieces may be sawed off as if of wood and the good section trimmed up and used in piecing out the line. If a multiple tile is broken it means a loss of several duct feet and little use can be made of the remainder. As the sections are long a very good alignment can be secured with fiber duct without the use of mandrels. The length also means fewer joints and eliminates greatly the danger of particles of concrete

sifting through and damaging the cable sheaths at some future time. Obstructions can be easily by-passed when in the path of the conduit line and when fiber duct is used.

In constructing conduit lines with fiber duct the construction is similar to that shown in the cross-section of Fig. 5. The ducts are separated by an inch of concrete and surrounded on the outside by an envelope 3 ins. thick. The trench is dug with sufficient width to allow the proper spacing and a 3-in. base of concrete is poured. The first tier of ducts is laid and held in place by a wooden rake designed to maintain the spacing. More concrete is

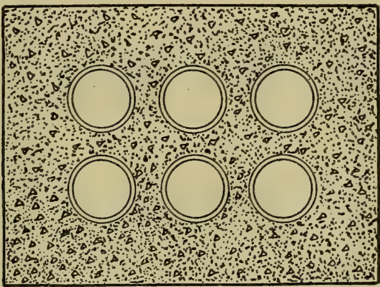


Fig. 5. Section of concrete conduit line using fiber duct.

poured and tamped into place and the second tier laid, and so forth, until the line is constructed. Between the tiers the joints are staggered, which tends to increase the strength of the finished line. The trench is dug according to the width of the line, so that no wooden forms are used and the concrete is poured and confined by the sides of the trench. The arrangement of the ducts in the line and the outside dimensions for 3.5 in. ducts are shown in the accompanying table.

TABLE IX. DIMENSIONS OF DUCT LINES USING 3.5 IN. FIBER DUCTS ARRANGED AS SHOWN IN FIG. 5.

Number of ducts	Number of ducts wide	Number of ducts high	Outside dimension, ins. width	Outside dimension, ins. height
4	4	1	25	10
6	3	2	20	15
9	3	3	20	20
12	4	3	25	20
16	4	4	25	25
20	4	5	25	30
24	4	6	25	35
30	6	5	35	30
36	6	6	35	35

The set of curves, Fig. 6, based on a 1:3:6 mixture for both 3-in. and 3.5-in. fiber ducts constructed as illustrated in Fig. 5 has been worked up by an Eastern central station company, and is used

TABLE X. 3-INCH WROUGHT-IRON PIPE LAID IN CONCRETE AND PROTECTED BY CREOSOTED WOOD

No. of ducts	No. of rows of ducts	Trench diam. in ins. width by depth below pavement (a)	Conduit line exclusive of splicing chambers and service boxes		Service boxes (c)	Splicing chambers (d)	Grand total	
			Labor	Material (b)			Per trench ft.	Cents per duct ft.
1	1	16 by 26	$0.507	$0.220	$0.568	....	$1.295	129.5
2	1	20 by 30	0.758	0.649	0.568	....	1.975	98.8
3	1	26 by 30	0.873	0.943	0.568	....	2.384	75.5
4	2	30 by 30	1.006	1.178	0.568	....	2.752	68.8
4	2	26 by 35	1.020	1.134	....	$0.384	2.538	63.5
5	2	26 by 35	1.086	1.389	....	0.384	2.859	57.2
6	2	35 by 35	1.148	1.507	....	0.384	3.039	50.7
7	2	36 by 35	1.335	1.757	....	0.420	3.512	50.2
8	2	36 by 35	1.360	1.930	....	0.420	3.710	46.4
9	3	30 by 40	1.405	2.172	....	0.450	4.027	44.7
10	3	36 by 40	1.535	2.359	....	0.450	4.344	43.4

NOTES: (a) — Add 8 in. for thickness of pavement; (b) — Pipe at 18 cts. per foot, tile duct at 6 cts. per foot; (c) — Service boxes every 55 ft.; (d) — Splicing chambers every 260 ft.

TABLE XI. 3-INCH TELEPHONE CONDUIT LAID IN CONCRETE AND PROTECTED BY CREOSOTED WOOD

No. of ducts	No. of rows of ducts	Trench diam. in ins. width by depth below pavement (a)	Conduit line exclusive of splicing chambers and service boxes Labor	Material (b)	Service boxes (c)	Splicing chambers (d)	Grand total Per trench ft.	Cents per duct ft.
4	1	30 by 36	$1.370	$0.615	....	$0.384	$2.369	$59.2
6	2	25 by 42	1.485	0.740	....	0.384	2.609	43.5
8	2	30 by 42	1.631	0.895	....	0.420	2.946	36.8
10	3	30 by 46	1.833	1.080	....	0.450	3.363	33.6
12	3	30 by 46	1.942	1.263	....	0.500	3.705	30.9
14	3	36 by 46	2.207	1.515	....	0.500	4.222	30.1
16	4	32 by 51	2.310	1.620	....	0.520	4.450	27.8
18	4	36 by 51	2.585	1.851	....	0.520	4.956	27.5
20	4	38 by 58	2.817	1.983	....	0.520	5.320	26.6
22	5	38 by 56	2.847	2.133	....	0.520	5.500	25
24	4	43 by 51	3.043	2.283	....	0.520	5.846	24.4
26	5	43 by 56	3.088	2.460	....	0.550	6.098	23 4
28	4	45 by 51	3.203	2.648	....	0.550	6.401	22.9
30	5	43 by 56	3.278	2.788	....	0.550	6.616	22.1
32	5	45 by 56	3.497	2.964	....	0.580	7.041	22.0
34	5	45 by 56	3.552	3.119	....	0.580	7.251	21.3
36	5	49 by 56	3.736	3.313	....	0.580	7.629	21.2
38	5	49 by 56	3.791	3.443	....	0.580	7.814	20.6
40	5	49 by 56	3.844	3.599	....	0.600	8.043	20.1

TABLE XII. CONSTRUCTION COST OF CONDUIT LINES OF SQUARE SINGLE DUCT CLAY CONDUIT ON RAILROAD RIGHT OF WAY. CONSTRUCTED IN CANADA. FULL CONCRETE ENVELOPE AND HALF INCH BETWEEN DUCTS

	Lineal feet	Duct lead	Excavation	Back filling	Concrete †	Conduits *	Foreman	Miscel.	Total per lin. ft.	Total per duct ft.	Total line cost
	245	12	$ 54.80	$ 8.52	$223.28	$252.43	$ 19.68	$ 26.51	$23.87	$0.1989	$ 858.22
	100	8	8.92	5.86	62.95	78.65	5.00	9.65	1.7103	.3138	171.03
	2346	12	310.65	137.47	1304.42	2301.44	117.30	222.17	1.8701	.1558	4391.45
	335	12	75.58	19.43	197.25	335.99	14.61	32.32	2.0153	.1679	675.18
	190	9	58.26	10.40	219.53	143.01	6.55	19.42	2.4060	.2674	457.17
	150	9	18.48	2.97	162.59	109.25	4.83	13.83	2.0797	.2311	311.95
	241	9	22.67	6.12	262.54	182.49	10.90	22.00	2.027	.2235	506.72
	238	9	11.78	11.08	233.60	176.53	10.29	20.98	1.9507	.2167	464.26
	135	9	1.25	.86	94.26	95.14	4.14	17.27	1.577	.1752	212.92
	154	9	1.25	1.40	113.51	109.74	4.73	17.20	1.6093	.1788	247.83
	250	6	16.88	21.40	156.01	126.12	7.67	27.33	1.422	.2370	355.41
	394	6	26.93	26.61	271 10	197 48	12.10	43.66	1.467	.2445	577.88
	326	6	50.46	26.70	247.36	204.72	12.10	43.66	1.485	.2475	585.00
	394	6	32.99	16.06	226.62	203.01	12.10	43.66	1.356	.2260	534.44
	394	6	48.60	18.42	255.26	211.80	12.10	43.66	1.497	.2495	589.84
	393	6	43.87	37.48	217.57	198.77	12.10	43.66	1.405	.2342	553.45
	394	6	45.32	29.10	233.50	195.25	12.10	43.66	1.418	.2363	558.93
	394	6	35.53	12.50	243.78	198.87	12.10	43.66	1.387	.2312	546.44
	394	6	28.10	9.75	279.17	201.90	12.10	43.66	1.458	.2430	574.68
	382	4	17.65	3.94	234.36	137.97	11 72	41.14	1.1696	.2924	446.78
	394	4	20.22	2.19	262.99	143 05	12.10	43.66	1.229	.8072	484.21
Totals	8243		$930.19	$408.26	$5501.65	$5803.61	$326.32	$862.76	.....	....	$13,730.79
Average per duct ft.			.0135	.0059	.0782	.0846	.0047	.0110	....	.23228	....

† Includes 50% duty paid on cement. * Includes 30% duty paid on conduits.

TABLE XII A

Excavation Cu. yd.	Excavation Line ft.	Back filling Cu. yd.	Back filling Line ft.	Concrete † Labor Cu. yd.	Concrete † Labor Line ft.	Material Cu. yd.	Material Line ft.	Conduits * per lineal foot Lay-ing	Conduits * per lineal foot Rod-ding	Conduits * per lineal foot Mate-rial	Fo'm'n Line Ft.	Miscl. per lineal foot Labor	Miscl. per lineal foot Mate-rial
$.481	$.222	$.078	$.034	$2.253	$.382	$3.088	$.529	$.205	$.036	$.785	$.08	$.054	$.054
.283	.089	.123	.059	4.452	.371	3.104	.259	.229	.030	.527	.05	.042	.054
.299	.132	.132	.059	2.773	.262	3.103	.294	.168	.024	.788	.05	.039	.051
.462	.226	.118	.059	2.698	.275	3.103	.315	.188	.0278	.787	.043	.034	.062
.571	.307	.102	.055	1.743	.442	3.084	.713	.148	.0200	.588	.0345	.050	.0502
.262	.122	.042	.019	1.534	.370	3.084	.713	.117	.0187	.592	.032	.036	.0573
.549	.091	.148	.025	1.609	.376	2.954	.678	.123	.0152	.588	.043	.032	.056
.58	.049	.546	.046	3.045	.486	3.09	.494	.152	....	.589	.043	.032	.0561
...	.009	...	.0066	2.124	.284	3.094	.414	.1104	....	.594	.0307	.0739	.054
...	.008	...	.0091	2.305	.314	3.093	.423	.1132	....	.599	.0307	.0547	.057
...	.0675	...	.086	2.141	.257	3.096	.367	.0976	.0073	.399	.0307	.0547	.0547
.364	.068	.36	.068	2.695	.3197	3.096	.368	.0874	.017	.395	.0307	.0547	.0544
.631	.128	.334	.068	2.187	.2597	3.096	.368	.0994	.023	.395	.0307	.0547	.0544
.388	.084	.189	.041	1.745	.2067	3.096	.368	.1074	.011	.395	.0307	.0547	.0544
.552	.123	.209	.047	2.356	.2797	3.096	.368	.1264	.014	.395	.0307	.0547	.0544
.498	.111	.426	.095	1.551	.1839	3.096	.368	.0994	.008	.395	.0307	.0547	.0544
.588	.115	.378	.074	1.891	.2237	3.096	.368	.0914	.007	.395	.0307	.0547	.0544
.487	.090	.171	.032	2.111	.2497	3.096	.368	.1004	.007	.395	.0307	.0547	.0544
.516	.071	.179	.025	2.867	.3387	3.096	.368	.0934	.0215	.395	.0307	.0547	.0544
...	.046	...	.0053	2.743	.2887	3.098	.325	.0886	.0065	.266	.0307	.0547	.053
.546	.051	.059	.0055	3.260	3.417	3.098	.325	.0924	.0063	.263	.0307	.0547	.0544

Average per duct foot cost: 12 duct line $0.1742, 9 duct line, $0.2154, 6 duct line $0.2658, 4 duct line $0.2998.

for estimating the material to be ordered for the job. For instance, for 100 trench feet of 12 3.5-in. ducts there would be required 8.75 cu. yds. of concrete made up from 9 barrels of cement, 4.25 cu. yds. of sand and 8.1 cu. yds. of stone.

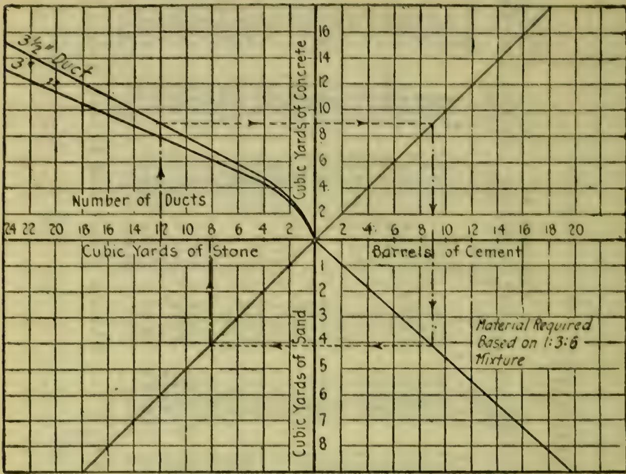


Fig. 6. Diagram for determining material required for installation of conduit using 1:3:6 mixture.

Cost of Underground Conduit Construction. The following data, from Electrical World, Dec. 14, 1912, bearing upon the cost of underground conduit construction in a New England city of 40,000 inhabitants are of interest, as the work was done with careful engineering and completed within the past three years. The total cost was $141,800, consisting of conduits, manholes and service ducts, $85,000; cables, $48,000, and miscellaneous expenses, $8,854. The items in detail were as follows:

CONDUITS, MANHOLES AND SERVICE DUCTS

23,393 ft. of conduits, containing 257,300 duct-ft. . .	$63,940	
141 manholes	16,600	
8927 ft. of service duct in 270 connections to buildings, poles, etc.	4,460	
		$85,000

CABLES

Street lighting:		
104,900 ft. of No. 6 cable	$14,400	
Secondary light and motor service:		
18,000 ft. of No. 4-0 cable, 30,000 ft. of No. 1-0 cable, 8000 ft. of No. 2 cable, 12,000 ft. of No. 6 cable	13,300	

7000 ft. of No. 1 bare wire, 15,000 ft. of No. 2 bare wire, 4000 ft. of No. 5 bare wire, 6000 ft. of No. 8 bare wire	$1,100	
Installation of above cables and wires, including materials, apparatus and supervision	9,200	
		$38,000
Primary lighting circuits:		
18,530 ft. of No. 2-0 cable, 12,450 ft. of No. 1-0 cable, 9780 ft. of No. 4 cable	$8,100	
Installation of these materials and supervision included	1,900	
		10,000
Miscellaneous expense on service connections to 73 poles and lamps and rewiring 197 buildings		8,854
Total		$141,854

The average cost of conduit was about 25 cents per duct-foot, including excavation, back-filling and conduit complete ready for cables, with maintenance of the street above the conduit for one year. The manhole walls were of brick, laid in cement, 8 in. to 12 in. in thickness, varying in depth from 3 ft. to 12 ft. Primary cables are installed in the same conduits as other service mains but in different ducts. Services averaged about 50 ft. in length, the individual costs running from 20 to 30 cents per foot.

Cost of Underground Conduits and Conduit Lines. Tables X and XI from Data, July, 1915, were contributed by C. D. Wesselhoeft. Tabulations give costs per trench foot of conduit lines under city streets, based on costs in New York City.

Vitrified Clay Conduits. Tables XII and XIII are from Data, September, 1911, contributed by The Clay Products Co.

TABLE XIII. CONSTRUCTION COSTS

PARTIAL CONCRETE ENVELOPE

Specifications: Top of construction 2 ft. below under surface of paving. Trench dug 5 ins. wider than conduit. Bed of concrete 2 ins. thick in bottom of trench. Joints made by linking with two dowel pins. Joint completely wrapped with perforated metal wrapper, cinched over top, sides and top of joint covered 2 ins. thick with cement mortar band 8 ins. wide. Lines built up as follows, with C. P. C. conduit:

2 ducts — 1 piece 2-way conduit.
3 ducts — 1 piece triangle 3-way conduit.
4 ducts — 1 piece 4-way conduit.
6 ducts — 1 piece 6-way conduit.
8 ducts — 2 pieces 4-way conduit

COSTS PER TRENCH AND DUCT FOOT

	2 ducts	3 ducts	4 ducts	6 ducts	8 ducts
Excavating and refilling...	.07540	.08801	.08944	.10036	.11362
Disposal of extra soil......	.00551	.00475	.01064	.01539	.02147
Cost of joint and laying conduit	.06990	.04490	.05310	.02867	.03329
Cost of concrete bed 2 ins. thick	.02682	.02682	.02682	.02682	.02682
Cost per trench foot	.17763	.16448	.20000	.17124	.18943
Cost per duct foot	.08881	.05482	.05000	.02854	.02368

COMPLETE CONCRETE ENVELOPE

Specifications: Top of construction 2 ft. below under surface of paving. Trench dug 6 ins. wider than conduit. Concrete envelope, 3 ins., entirely surrounding conduit. Two dowel pins to each of multiple. Joints of multiple wrapped with burlap saturated in creosote. Where line is built up ½ in. of concrete between pieces, Concrete mixture 1, 3, 5. Lines built up as follows, with C. P. C. conduit:

1 duct — 1 square or round-duct single conduit.
2 ducts — 1 piece 2-way conduit.
3 ducts — 1 piece triangle 3-way conduit.
4 ducts — 1 piece 4-way conduit.
5 ducts — 1 piece 2-way conduit below and one piece triangle 3-way conduit above.
6 ducts — 1 piece 6-way conduit.
8 ducts — 2 pieces 4-way conduit.

COSTS PER TRENCH AND DUCT FOOT

	1 duct	2 ducts	3 ducts	4 ducts	6 ducts	8 ducts
Excavating and refilling..	.05330	.07540	.08801	.08944	.10036	.11362
Disposal of extra soil....	.00266	.00551	.00475	.01064	.01539	.02147
Laying of conduit in concrete	.14125	.18188	.16500	.22100	.25535	.31382
Total cost per trench foot	.19721	.26279	.25776	.32108	.37110	.44891
Total cost per duct foot.	.19721	.13139	.08592	.10703	.06185	.05611

Vitrified Clay Conduit. Mr. C. H. Judson gives comparative cost, maintenance and depreciation on one mile of 400 pair telephone cable, underground construction vs. aerial construction.

Construction Cost:		
Four-duct conduit with manholes and distributing poles, with total capacity of 2,000 pairs..	$5,300.00	
Forty-five-foot pole line with ½-in. messengers and distributing poles, with capacity 800 pairs	2,200.00	
Extra cost of underground over aerial........		$3,100.00
One four-hundred-pair cable installed in duct.	$6,000.00	
Two two-hundred-pair cable installed on messenger	6,000.00	
Maintenance, Depreciation and Interest (Annual).		
2% depreciation, ¼ of 1% maintenance on conduit line	120.00	
10% depreciation, 1% maintenance on poles and messengers	242.00	
Extra cost of maintenance of aerial over conduit line		122.00
Depreciation of aerial cable at 5% more than underground		300.00
Annual extra maintenance cost of aerial over underground		$422.00
If the added construction cost for underground was borrowed at 6%, or		186.00
The conduit line would show an annual net saving of		$236.00

The conduit line will be ready to receive 1,600 pairs more at a slight cost any time in the next hundred years, and the aerial line will need rebuilding at least twice.

Vitrified Clay Conduit. Data gives the following comparative costs of 3-duct line showing economy of triangle 3-way.

	Single duct	Flat 3-way laid flat	Flat 3-way laid on edge	Triangle 3-way
Excavating and refilling	$0.16822	$0.18698	$0.18720	$0.15080
Disposal of extra soil.........	.02223	.03097	.02907	.01558
Cartage of conduit to trench..	.01800	.01500	.01500	.01200
Cost of laying in concrete......	.15607	.26454	.25319	.10959
Cost joint material per trench foot	.00000	.00750	.00750	.00500
Cost per trench foot	$0.36452	$0.50499	$0.49196	$0.29297
Cost per duct foot	.12151	.16833	.16399	.09766

Underground Conduit. Mr. Edward N. Lake gives the following comparative costs of using single duct vitrified clay tile, in the Journal of Western Society of Civil Engineers, June, 1910.

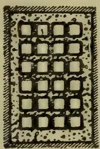


Fig. 7

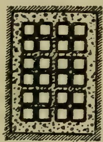


Fig. 8.

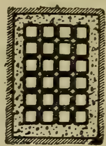


Fig. 9.

Comparative estimates of cost per duct foot in cents. Chicago conditions.

Conduit Section	4	6	8	9	10	12	15
Std. single duct (Fig. 7)..	27.6	22.0	19.3	18.3	18.0	16.4	15.0
Single duct in multiple (Fig. 8)	27.6	22.1	19.7	...	19.6	17.7	...
Single duct in tiers (Fig. 9)	28.1	23.0	20.4	19.3	19.2	17.5	16.3

Conduit Section	16	18	20	24		
Std. Single duct (Fig. 7)....	14.9	14.6	14.2	13.3	Average	17.60
Single duct in multiple (Fig. 8)	15.6	...	15.1	14.3	"	18.96
Single duct in tiers (Fig. 9).	16.0	15.9	15.3	14.5	"	18.68

Cost of Electric Conduits for Various Conditions. Mr. L. A. Ferguson in Proceedings National Electric Light Association, 1911, has given the following costs, Table XIV, for several types of conduit laid under different kinds of pavement and in various groups.

Underground Conduit: Electric Costs — 1913 — Panama Pacific Exposition. The following unit costs are the actual contract prices quoted and accepted, and were compiled from Electrical Record by Krehbiel Co., Chicago.

TABLE XIV. COST PER DUCT FOOT IN DIFFERENT GROUPS

Kind of pavement	Groups of 2 or 4, cents	Groups of 6 or 9, cents	Groups of 12, 16 or 20, cents	Groups of 25 or 30, cents	Groups of 40, 50 or 60, cents
NATIONAL CONDUIT					
No pavement	16.74	16.74	16.74	16.74	16.74
Cedar	22.81	19.27	18.07	17.56	17.31
Cedar, conc. base	26.86	20.95	18.94	18.11	17.69
Granite	26.86	20.95	18.94	18.11	17.69
Granite, conc. base	36.99	25.17	21.14	19.49	18.64
Macadam	21.46	18.70	17.77	17.28	17.18
Asphalt	57.24	33.61	25.55	22.24	20.66
FRANCIS CONDUIT					
No pavement	14.66	14.66	14.66	14.66	14.66
Cedar	20.73	17.19	15.99	15.48	15.23
Cedar, conc. base	24.78	18.87	16.86	16.03	15.61
Granite	24.78	18.87	16.86	16.03	15.61
Granite, conc. base	34.91	23.09	19.06	17.41	16.56
Macadam	19.38	16.62	15.69	15.30	15.10
Asphalt	56.16	31.53	23.47	20.16	16.48
CAMP TILE					
No pavement	14.14	14.14	14.14	14.14	14.14
Cedar	20.21	16.67	16.47	14.96	14.71
Cedar, conc. base	24.26	18.35	16.34	15.51	15.09
Granite	24.26	18.35	16.34	15.51	15.09
Granite, conc. base	34.39	22.57	16.54	16.89	16.04
Macadam	18.66	16.10	16.17	14.78	14.68
Asphalt	54.64	31.01	22.95	19.64	17.96
LITHOCITE CONDUIT					
No pavement	15.18	16.16	15.18	16.18	15.18
Cedar	21.25	17.71	16.51	16.00	15.75
Cedar, conc. base	25.30	19.39	17.38	16.55	16.13
Granite	25.30	19.39	17.38	16.55	16.13
Granite, conc. base	35.43	23.61	19.58	17.93	17.08
Macadam	19.90	17.14	16.21	16.82	16.62
Asphalt	55.68	32.05	23.99	20.68	19.00
THREE-INCH IRON PIPE					
No pavement	25.5	25.5	25.5	25.5	25.5
Cedar	31.57	28.03	26.83	26.32	26.07
Cedar, conc. base	35.62	29.71	27.70	26.87	26.45
Granite	35.62	29.71	27.70	26.87	26.45
Granite, conc. base	45.75	33.93	29.90	28.25	27.40
Macadam	30.22	27.46	26.53	26.14	25.94
Asphalt	66.00	42.37	34.31	31.00	29.32

EXHIBITS BUILDING SECTION

Installing 3-in. inside diameter wood fibre direct in standard concrete construction, conduit section 12 to 24 ducts, at 11 cts. per duct foot.

Installing 3-in. inside diameter wood fibre duct in adopted wood box construction; conduit section 18 to 21 ducts, at 8.65 cts. per duct foot.

Installing 3-in. inside diameter wood fibre duct in adopted wood

box construction; conduit section 10 to 15 ducts, at 9.91 cts. per duct foot.

Installing 3-in. inside diameter wood fibre duct in adopted wood box construction; conduit section 4 to 8 ducts, at 12.33 cts. per duct foot.

The average cost of installing 3-in. wood fibre duct in wood box construction is 10.3 cts. per duct foot.

The above prices are based on approximately 25,000 trench feet of conduit consisting of 281,000 duct feet of 3-in. wood fibre duct and 1,700 ft. of 3-in. black iron pipe. Of this amount of conduit, 2,700 conduit feet, or 59,300 duct feet, will be laid in standard concrete construction, the remainder excepting the iron pipe will be installed in the adopted box construction.

Average depth of concrete construction will be 4 ft. 3 ins. to center of lowest duct; cross section will run from 4 wide and 3 high to 4 wide and 6 high in concrete; and from 2 wide and 2 high to 7 wide and 3 high in wood construction.

In the wood box construction adopted, the duct will be aligned by filling the box with sand, except for a distance of 4 ft. at manholes where concrete will be used. Box will be covered with planking, well nailed and running across the short dimension of the box. The bottom boards will be reinforced by means of splice plates and tied together with corner straps of sheet metal.

STATES AND FOREIGN SITES SECTION

Installing twelve 2-in. and six 3-in. inside diameter wood fibre duct in wood box construction at $1.47 per conduit foot.

Installing six 2-in. and three 3-in. inside diameter wood fibre duct in wood box construction at 76.5 cents per conduit foot.

Installing three 4-in. and three 2-in. inside diameter wood fibre duct in wood box construction at 76.5 cents per conduit foot.

The average cost, in place, for installing 3-in. wood fibre duct ranging in sections as given above, is 13 cents per duct foot.

The above costs are based on 10,000 trench feet of conduit composed of 2-in. and 3-in. wood fibre duct with .125-in. walls and slip sleeves. It will require approximately 41,000 duct feet of 2-in. and 31,000 duct feet of 3-in. duct. The average section will be three ducts wide and two ducts high.

EXHIBITS BUILDING SECTION

Manholes of timber construction ranging in size from 5 by 6 ft. and 5 ft. deep at $36.00 each to 7 by 8 ft. and 6 ft. deep at $65.00 each. Average $49.30 each in place.

Manholes of concrete construction ranging in size from 7 by 7 ft. and 7 ft. deep to 8 by 8 ft. and 7 ft. deep, average $129.30 each in place, exclusive of cast iron cover which is furnished by the Exposition Company.

STATES AND FOREIGN SITES SECTION

The actual prices of the shallow type of wooden manholes used

in this section range from $20.00 to $27.00 each, and average $25.00 each in place.

In the general system for the exposition there will be approximately 150 manholes. Thirteen of this number will be of standard concrete construction with cast iron covers. The remainder will be of wood construction. Maximum duct in any conduit run to manholes — 24.

Cost of Repairing Openings in Pavements. The following data are from a report on Pavements of Akron, Ohio, made by the Municipal University of Akron and were published in Engineering and Contracting, Oct. 7, 1914.

TABLE XV. COST OF REPAIRING OPENINGS MADE IN CINCINNATI PAVEMENTS, ACCORDING TO SIZE OF OPENING AND TYPE OF PAVEMENT

	Size of opening, sq. yds.	Surface, sq. yds.	Concrete, cu. yds.	Total cost	(1) Extra material	(2) Average cost per sq. yd.	(3) Avg. cost per sq. yd. overhead included
ASPHALT	1	304.8	63.95	$928.51	$3.67	$1.83	$2.29
	2	502.4	116.69	1,396.22	.....	1.68	2.10
	4	805.9	176.74	1,530.07	.....	.67	.84
	8	354.5	67.83	623.90	.....	.69	.86
	12	732.1	65.50	885.72	.....	.74	.93
	50	3,784.1	131.15	3,385.88	.....	.89	1.11
		6,483.8	621.86	$8,750.30	$3.67	$ .85	$1.16
WOOD BLOCK	1	33.5	8.21	$92.57	.....	$1.39	$1.74
	2	80.6	13.18	223.18	.....	1.85	2.31
	4	123.1	24.93	317.20	$8.75	1.06	1.33
	8	77.1	16.79	137.34	.....	.56	.70
	12	219.1	22.09	377.24	15.05	1.12	1.40
	50	1,419.0	.....	1,632.88	44.00	1.12	1.40
		1,952.4	85.20	$2,780.42	$67.80	$1.18	$1.48
BITUMINOUS MACADAM (Penetration)	1	54.0	.....	$88.96	$18.76	$1.30	$1.63
	2	106.7	.....	133.22	29.51	.97	1.21
	4	209.0	.....	237.39	52.00	.89	1.11
	8	73.5	.....	77.23	15.25	.84	1.05
	12	207.1	.....	244.28	46.75	.95	1.19
	50	140.2	.....	111.72	38.00	.53	.66
		790.5	.....	$893.80	$200.27	$ .88	$1.10
GRANITE	1	683.0	55.67	$1,236.13	$18.82	$1.38	$1.66
	2	1,071.1	146.03	2,120.21	33.99	1.20	1.50
	4	1,832.8	238.13	3,352.84	51.77	1.07	1.34
	8	1,189.7	135.82	1,947.15	43.08	.96	1.10
	12	3,193.3	208.56	3,889.75	90.16	.84	1.05
	50	29,202.4	727.53	20,547.63	569.95	.56	.70
		37,172.3	1,511.74	$32,953.71	$802.27	$ .65	$ .81

	Size of opening, sq. yds.	Surface, sq. yds.	Concrete, cu. yds.	Total cost	(1) Extra material	(2) Average cost per sq. yd.	(3) Avg. cost per sq. yd. overhead included
MACADAM	1	344.5	.....	$331.65	$108.02	$ .65	$ .81
	2	2,080.6	.....	1,412.61	472.43	.45	.56
	4	2,926.9	.....	1,450.38	474.21	.33	.41
	8	619.9	.....	341.66	76.55	.43	.54
	12	1,127.1	.....	515.33	190.63	.29	.36
	50	14,237.6	.....	3,809.83	1,110.65	.19	.24
		21,336.6	.....	$7,861.46	$2,432.49	$ .25	$ .31
BOWLDERS	1	133.1	.....	$ 167.71	$3.85	$1.23	$1.54
	2	531.4	.....	528.67	14.81	.95	1.21
	4	279.2	.....	809.17	20.78	.81	1.01
	8	392.3	.....	193.95	7.52	.67	.84
	12	621.6	.....	533.95	27.20	.82	1.03
	50	2,297.3	.....	1,506.69	52.51	.63	.79
		4,834.2	.....	$3,740.14	$126.67	$ .75	$ .94
BRICK	1	304.9	41.78	$786.81	$15.43	$1.76	$2.20
	2	816.5	117.29	1,691.26	17.63	1.24	1.55
	4	1,066.8	149.17	1,360.54	45.51	.92	1.15
	8	393.2	55.66	612.79	15.13	.73	.91
	12	700.3	97.38	1,078.14	25.26	.78	.98
	50	5,720.3	96.59	5,224.20	228.43	.82	1.03
		9,001.1	557.87	$11,253.74	$347.39	$ .89	$1.11

NOTES.— (1) Material chargeable to party permit is issued to through material being destroyed or misplaced when cut is made in pavement. (2) Includes only direct cost of labor and material actually applied on the job, as shown by the foremen's reports, which are made daily to office. During 1913 all new material was used in mixing concrete, no old material being used. The price of concrete varied from $7 in the small cuts to $6 per cu. yd. in the larger size. The prices given arrived at by deducting cost of concrete at above mentioned prices from total cost, which remainder represented actual direct cost of restoring pavement surface. (3) The same as preceding column, with addition of 25 per cent. overhead, which represents difference between the total expenditures of department and amount expended directly for labor and material, as shown by reports of foremen doing work.

Cost of Trench Work Through Brick Pavement for Wire Conduit. An article in Engineering and Contracting, June 2, 1915, by Mr. F. L. Shidler, says: The trench was as near as possible to the curb and crossed under two sets of street car tracks and two street intersections. The costs given are for tearing up brick pavement down to grout base, trenching sand cushion and replacing same, relaying brick pavement and slushing with cement filler for laying a wire conduit for ornamental street lights. They also include the cost of sixteen 1 ft. 4 in. square holes about 16 ins. deep, cut through cement and stone sidewalks, filling these holes with con-

crete and setting four base bolts in each hole. The cost for the post holes, etc., was as follows:

Item	Total	Per hole
Labor cutting, 25 hrs. at 50 cts.	$12.50	$0.78
Labor concreting	5.00	0.31
Total labor	$17.50	$1.09
12 wood templets for base bolts	3.00	0.19
2 cu. yds. concrete at $3.60	7.20	0.45
Miscellaneous	1.12	0.07
Total materials, etc.	$11.32	$0.71
Grand total	$28.82	$1.80

The cost of the trench 1½ ft. wide and 1,130 ft. long was as follows:

Item	Total	Lin. ft.
Tearing up and cleaning brick	$21.37	$0.019
Relaying brick	27.95	0.025
Teaming	4.00	0.004
Total labor	$53.32	$0.048
2 cu. yds. cushion sand	3.00	.....
4 bbls. cement	6.00	.....
300 new brick	4.00	.....
Miscellaneous	5.00	.....
Total materials	$18.00	$0.016
Grand total	$71.32	$0.064

Armored Cable Versus Conduit Systems. Electrical World, Jan. 11, 1913, says: Conduit systems have long occupied an almost exclusive field whenever overhead lines were to be placed underground, no other underground method being available. Armored cable, however, is beginning to get a foothold, not as a direct substitute for the conduit system but rather in a field of its own which covers one particular phase of underground systems. This field includes the smaller cities, suburban districts, parks, private residences and manufacturing plants where the buildings are spread over a considerable area. The tungsten lamps in the New York City parks, for instance, are fed with energy through armored cable laid in the ground. Installations of this sort where the service rendered is comparatively small do not warrant a large expenditure to increase the fixed charges. The following figures recently submitted by the Simplex Electrical Company of Boston show the cost of the lead-covered cable in ducts and also of the armored cable laid directly in the ground:

COST OF LEAD-COVERED CABLE LAID IN DUCTS

1000 ft. No. 6 three-conductor, rubber insulated, lead-covered cable (600-volt service)	$175
1000 ft. conduit	55
Cost of laying, including cost of two manholes and drawing in and splicing cable	450
	$680

COST OF STEEL-TAPED CABLE LAID IN GROUND

1000 ft. No. 6 three-conductor, rubber-insulated, lead-covered steel-taped cable (600-volt service)	$240
Cost of laying	50
	$290

The figures do not include the cost of relaying the pavement. This, while approximately the same in either case, will be somewhat more for the conduit installation than for the armor cable, because the trench for the ducts would need to be wider and deeper in order to have the ducts far enough underground.

As noted in the table, the difference in cost is mainly due to the much larger expenditure needed for the installation of the duct system. The armored cable itself costs only a nominal sum more than the regular lead-covered cable and its installation is very simple, consisting merely of laying this ready-made conduit system directly in a shallow trench and replacing the earth over the cable. The construction of conduit system with its necessary manholes requires plans from which to work and expert superintendence during its construction. In addition to this the cost which is involved by drawing the lead cable into the ducts must be taken into consideration.

Comparative Costs of Tile and Fiber Conduit. From Electric Railway Journal, Dec. 16, 1911, we take the following: William D. Ligon has prepared the comparison of costs of tile and fiber conduits presented in Tables XVI to XVIII. These figures are based upon actual conditions in St. Louis, Chicago and other cities of the Central West. As shown in the Tables the cost of constructing multiple duct tile is less than that of constructing single duct tile, owing principally to the less amount of excavating, refilling, paving, dirt disposal and concreting. This saving ranges from $0.031 to $0.285 and even more per trench foot, according to the number of ducts. Table XVIII, however, shows that much greater economy is possible by using fiber conduit, the cost per trench foot of one pipe to sixteen-pipe installations ranging from $0.44 to $2.422, as compared with $0.483 to $2.723 for the multiple duct tile. This saving is due to the lower cost of the fiber conduit as delivered, to its greater ease in installation, to the elimination of breakage losses and to the simpler connections.

Cost of Manholes. The following is taken from cost data compiled by Mr. Borroughs, Engineer of the Washington Commission.

Cubical contents	Cu. yards, concrete	Ratio, concrete to contents
47	1.0	.021
84	2.0	.024
104	2.5	.024
144	4.6	.032
182	5.0	.027

Say, 0.025 cu. yd. of concrete or brick masonry per cubic foot of inside measurement. For this purpose all masonry will be con-

TABLE XVI. COST TO CONSTRUCT MULTIPLE DUCT TILE CONDUIT IN STREETS PAVED WITH GRANITE, OR EQUIVALENT PAVING, EXCLUSIVE OF MANHOLES

Duct Sections	1	2	3	4	8	12	16	20	24
Excavating, refilling, paving and disposal of dirt	$ .230	$ .361	$ .546	$ .397	$ .590	$ .637	$ .791	$ .867	$ .939
Concrete	.104	.131	.152	.160	.243	.269	.333	.368	.384
Cost tile delivered	.053	.106	.159	.212	.424	.636	.848	1.060	1.272
Laying tile	.030	.040	.060	.080	.160	.240	.320	.400	.480
Cleaning ducts	.005	.010	.015	.020	.040	.060	.080	.100	.120
Water, bridging and shoring	.005	.007	.010	.012	.025	.030	.040	.050	.060
Tool repairs and replacement	.010	.010	.010	.012	.025	.030	.040	.050	.060
Incidentals	.010	.010	.010	.010	.015	.018	.024	.030	.036
Supervision, inspection and timekeeping	.036	.052	.072	.072	.114	.192	.247	.292	.339
Total per trench foot	.483	.727	1.034	.975	1.636	2.112	2.723	3.217	3.690

TABLE XVII. COST TO CONSTRUCT SINGLE DUCT TILE CONDUIT IN STREETS PAVED WITH GRANITE, OR EQUIVALENT PAVING, EXCLUSIVE OF MANHOLES

Duct Sections	1	2	3	4	8	12	16	20	25
Excavation, refilling, paving and removing surplus earth	$ .259	$ .353	$ .494	$ .430	$ .722	$ .788	$ .858	$ .996	$1.072
Concrete	.105	.145	.185	.192	.287	.348	.412	.474	.540
Cost tile delivered	.054	.108	.162	.216	.432	.648	.864	1.080	1.350
Laying tile	.030	.060	.090	.120	.240	.360	.480	.600	.750
Cleaning ducts	.005	.010	.015	.020	.040	.060	.080	.100	.125
Water, bridging and shoring	.005	.007	.010	.012	.025	.030	.040	.050	.062
Tool repairs and replacement	.010	.010	.010	.012	.025	.030	.040	.050	.062
Incidentals	.010	.010	.010	.010	.015	.018	.024	.030	.037
Supervision, inspection and timekeeping	.036	.053	.073	.076	.134	.171	.210	.253	.299
Total per trench foot	.514	.756	1.049	1.088	1.920	2.453	3.008	3.633	4.297

TABLE XVIII. COST TO CONSTRUCT FIBER PIPE CONDUIT IN STREETS PAVED WITH GRANITE, OR EQUIVALENT PAVING, EXCLUSIVE OF MANHOLES

Duct Sections	1	2	3	4	8	12	16	20	25
Excavation, refilling, paving and removing surplus earth	$ .230	$ .343	$ .431	$ .381	$ .601	$ .655	$ .716	$ .848	$ .919
Concrete	.090	.126	.163	.175	.273	.344	.417	.490	.572
Cost fiber pipe delivered	.051	.102	.153	.204	.408	.612	.816	1.020	1.275
Laying fiber pipe	.010	.020	.030	.040	.080	.120	.160	.200	.250
Proving ducts	.003	.005	.007	.010	.020	.030	.040	.050	.062
Water, bridging and shoring	.005	.007	.010	.012	.025	.030	.040	.050	.062
Tool repairs and replacement	.010	.010	.010	.012	.025	.030	.040	.050	.062
Incidentals	.010	.010	.010	.010	.015	.018	.024	.030	.037
Supervision, inspection and timekeeping	.031	.047	.061	.063	.101	.138	.169	.205	.243
Total per trench foot	.440	.670	.875	.907	1.548	1.977	2.422	2.943	3.482

sidered as concrete. Considering concrete proportions as 1-2.5-5 one yard of concrete will call for,—

1.13 barrels of cement @ $2.85	$ 3.22
0.40 yards of sand " 1.25	.50
0.80 yards of gravel " 1.50	1.20
Incidentals, such as lumber, etc.	3 00
Labor	2.08
	$10.00

0.025 yards at $10.00 gives $.25 per cubic foot of contents as the cost of concrete.

Excavation in gravel will be taken out one foot larger all around than the outside measurements, and two feet more in depth than the minimum inside depth. For the manhole whose contents = 104 cu. ft. the excavation will be: —

9 ft. 2 ins. x 6 ft. 8 ins. equals 13.5 cubic yards.

It will be necessary to shore the excavation with 3 in. x 12 in. planks, 8 ft. long. Thirty-six planks will be needed and the salvage will be 50%. Hence the expense will be,—

18 ft. 3 ins. x 12 ins. x 8 ft. equals 432 F. B. M.

The total expense will be,—

Excavating and removing 13.5 cu. yds. of gravel	@ $1.50	$20.25
Shoring in place, 432 ft. B. M.	@ 25.00	10.80
		$31.05
Plus 10% for teaming, etc.		3.10
		$34.15

$34.15 divided by 104 equals .328 per cu. ft., say 35 cents. This, added to the cost of masonry, gives a total of 60 cents. The rule used will be:

The cost of manholes in gravel will be 60 cents per cubic foot of the contents, using minimum inside dimensions. To this must be added $15.10 for cover and casting.

In rock excavation it will be impossible to take out the material to neat lines, hence, two feet over the outside measurements will be used, with 2.5 feet more depth than the minimum inside depth. The excavation will be, in this case,

11 ft. 2 ins. x 8 ft. 8 ins. equals 23.1 cu. yds.

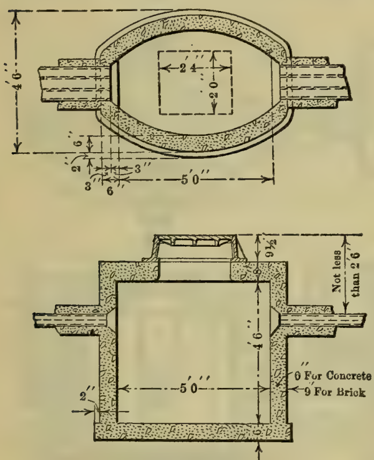
No shoring will be necessary, so the cost will be:

Excavating and removing 23.1 yds. of rock @ $3.00	$69.30
Plus 10% for teaming, etc.	6.93
	$76.23

$76.23 divided by 104 equals $.733 per cu. ft. of contents. Calling this 75 cents and adding 25 cents for masonry, gives a cost of $1.00. The rule used will be: —

The cost of manholes in rock will be $1.00 per cubic foot of contents, using minimum inside dimensions. To this must be added $15.10 for cover and casting.

Vault or Manhole Construction. Telephone Construction, by C. Mayer, has the following: The location of a vault shall be barricaded and excavation then made to such a depth as to bring the bottom of the concrete top 17.5 ins. below street grade. If the vault is built in advance of street improvements, the necessary information as to grade shall be obtained from the city engineer. The excavation for brick vaults shall be sufficiently wide and long



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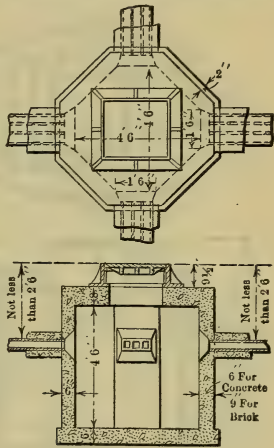

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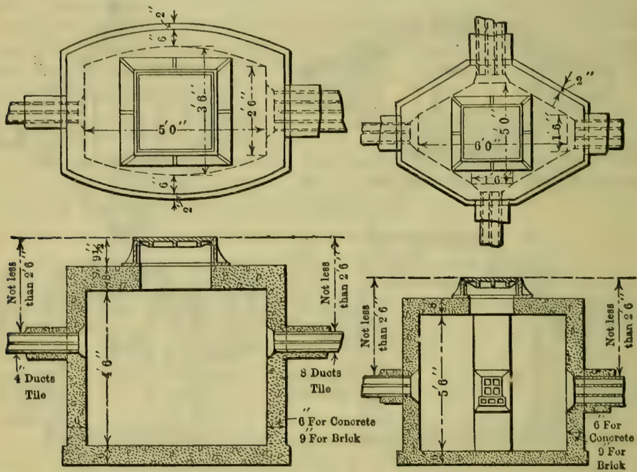
Fig. 10. Vault size 1 to be used on runs of 1 to 3. Ducts of conduit when not intersected.

Fig. 11. Vault size 2 to be used on runs of 1 to 3 ducts of conduit when intersected.

enough to leave a space of 6 ins. around the outside of the wall of the manhole when finished.

In stiff clay, the excavation may be made of the outside dimensions of the vault. The standard manhole or vault shall be of either brick with a concrete bottom, concrete top and cast iron frame and cover, or of concrete throughout, with cast iron frame and cover. In size it shall be approximately of the inner dimensions specified on the plan of the work. For straight runs the long dimensions of the vault shall be in the line of conduit. For intersections the long dimension of the vault shall be in the line of the heavier run. For different cross sections of conduit the desirable forms and dimensions for vaults are shown by Figs. 10 to 20 inclusive.

In constructing a vault the bottom of the excavation shall first be tamped and a layer of concrete of the depth shown on vault drawing, and of sufficient width and length to project 2 ins. beyond the foundation courses of brick, or the bottom of the concrete wall shall be placed, tamped and graded for drainage. A sewer connection or other means of drainage shall be provided wherever possible. If the vault is located on high, well-drained, sandy soil, drainage may be secured by placing one or two lengths of 6-in. sewer tile perpendicularly into the ground from the bottom of the vault. Where possible the vault shall be drained by a 6-in. sewer



12 13

Fig. 12. Vault size 3 to be used on runs of 4 to 8. Ducts of conduit when not intersected.

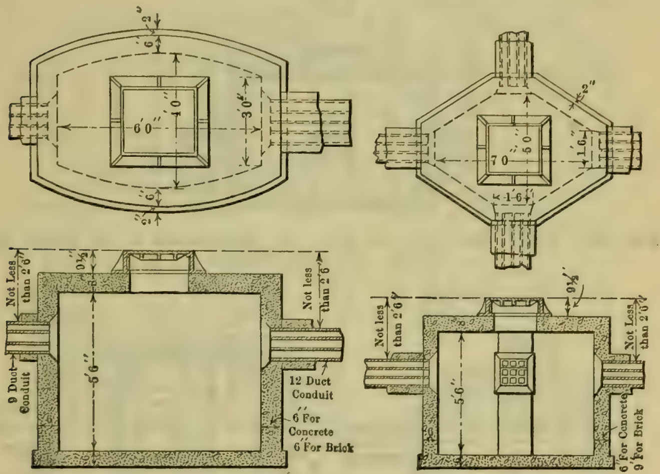
Fig. 13. Vault size 4 to be used on runs of 4 to 8 ducts of conduit when intersected.

"P" trap in the bottom of the vault with 6-in. sewer tile connection to the sewer. If the water level of the sewer is higher than the bottom of the vault, sewer connections may be made through the wall of the vault using a running sewer trap. A back water trap shall be installed in all cases where the bottom of the vault is less than 3 ft. above the top of the sewer, by which the vault is to be drained. All drainage openings shall be provided with cast iron strainers set flush with the floor or wall of the vault. Where the vault is drained through the floor, the floor shall be laid so as to drain to the trap with a fall of not less than 1 in. in 10 ft.

In the case of brick vaults, the wall of the vault shall be built up of hard burned sewer brick laid in cement mortar. In dry

weather brick shall be well moistened before using. Walls shall be 9 ins. thick. The wall shall be built up, every sixth course being laid as headers, to the height required. The top course shall be laid as stretchers. The horizontal mortar joints shall not exceed .5 in. and the vertical joints .375 in. in thickness.

The brick work shall be racked away around the entrance of the ducts to afford room for turning cables when installed. As the walls are built up cable support nipples of approved type shall be installed in all vaults. No less than two supports shall be set in the walls parallel to the conduit run on a level with each layer of



14 15

Fig. 14. Vault size 5 to be used on runs of 9 to 12. Ducts of conduit when not intersected.

Fig. 15. Vault size 6 to be used on runs of 9 to 12. Ducts of conduit when intersected.

ducts in non-intersected vaults. The supports shall not be nearer than 1 ft. from the end of the conduit and shall be placed symmetrically. All pipes entering the vaults shall be well cemented into the brick work and the inside of the vault walls well pointed up.

When vaults are intersected at least one support nipple shall be set in each wall between conduit runs on a level with each layer of ducts and set as nearly as practicable at the central point.

The walls of all concrete vaults shall be 6 ins. thick. The concrete in the roof and floor shall be thoroughly tamped. The concrete in the walls shall be uniformly and equally distributed within the forms, in layers not exceeding 6 ins. in thickness, each layer being thoroughly tamped in place. After this the succeeding layer

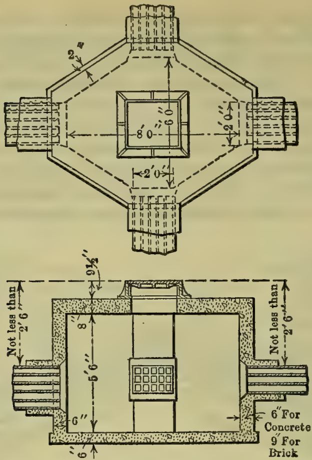
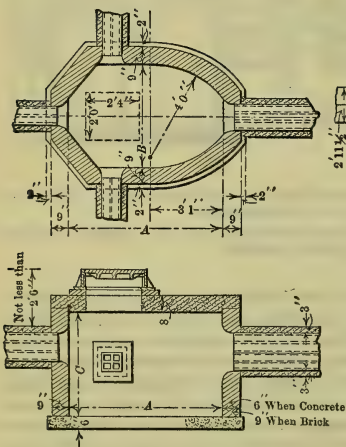


Fig. 16. Vault size 8 to be used on runs of 13 to 24 ducts of conduit when intersected.



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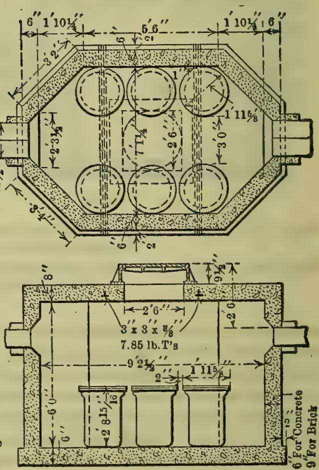

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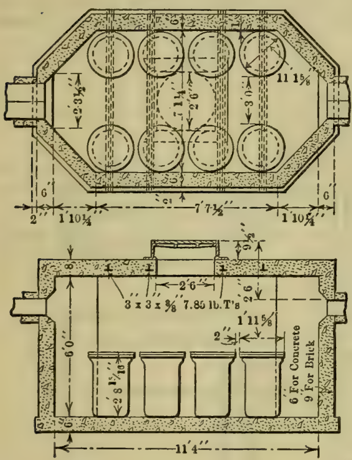
Fig. 17. Vault size 9, to be used on conduit runs —?

Fig. 18. Vault size 10, used for installing 6 loading pots on conduit runs when not intersected.

shall be at once applied, and the operation continued until the walls have reached the required height.

When the walls of the vault are finished and filled in and around the outside, the wood form for the concrete top shall be placed. The form shall be placed so as to make the center of the manhole opening as nearly as possible over the center line of the ducts, going both ways, and midway between the ends of the vault; the long edge of the opening being parallel to the main line of conduit.

In case a vault top is 7 ft. or more in length it shall be



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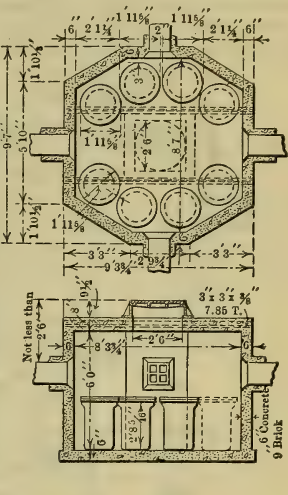

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Fig. 19. Vault size 11, used for installing 8 loading pots on conduit runs when not intersected.

Fig. 20. Vault size 12, used for installing 6 to 8 loading pots on conduit runs when intersected.

strengthened by .375-in. x 3 x 3-in. T-iron or other equivalent reinforcing irons, placed approximately 2 ft. apart and parallel to the short side of the vault top. Where T-irons are used they shall be imbedded in the concrete with the stem of the T up and the bottom of the bar within 1 in. of the lower side of the concrete. An alternative method for reinforcing concrete roofs of vaults shall be as follows: .5-messenger strand shall be cut to the outside width and length of the vault roof and shall be set in the concrete on 4-in. centers about 1 in. from the bottom of the concrete roof, both across the length and width of the roof. Immediately under the center of the bearing surface of the vault frame shall be placed

two pieces of .5-in. strand side by side both lengthwise and across the width of the vault roof.

The forms used for building vault tops are shown by Fig. 21. In the case of concrete vaults openings for the entrance of the ducts shall be made with the forms shown by Fig. 22. These forms are made in two styles, collar and block. The collar form shall be used where the ducts are already installed, and the block form, where it is desired to leave an opening for the entrance of future ducts. The collar form shall be placed just over the ducts and against the vault form as shown on Fig. 21, and shall be removed after the vault form has been removed.

The forms shown by Fig. 23 shall be used to form openings for the entrance of sewer tile where it is desirable to have a beveled

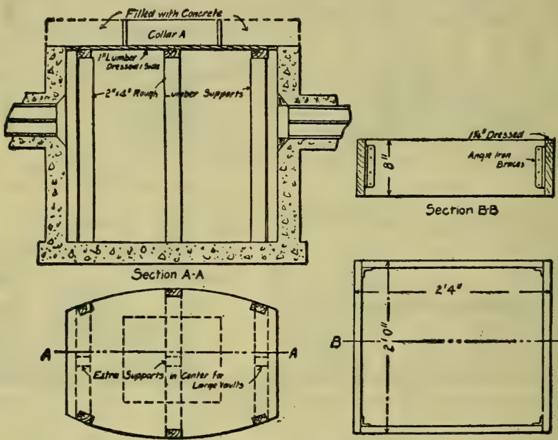


Fig. 21. Forms for building vault tops.

opening as in some cases where large cable is to be installed in the sewer tile. These forms are also used to form openings for the entrance of circular ducts.

The method of mixing concrete shall be the same as described for conduit. The proportions of concrete mixtures for vaults shall be as follows: If crushed stone concrete is used: For floors of vaults, 1 part American Portland cement, 4 parts .25-in. screenings and 8 parts No. 3 (.75-in) stone; for roofs and sides of vaults, 1 part American Portland cement, 3 parts .25-in. screenings, and 5 parts No. 3 (.75-in.) stone. If gravel concrete is used: For floors of vaults, 1 part American Portland cement, 4 parts sand and 8 parts of gravel; for roofs and sides of vaults, 1 part American Portland cement, 3 parts sand and 5 parts gravel.

Cement mortar shall be mixed on a closely laid timber platform

or in a wood box. The sand shall be spread on the mixing platform to a thickness of 2 ins., the cement added and evenly distributed and the materials turned over 3 times with hoes. Sufficient water to make the mortar into a stiff paste shall then be carefully

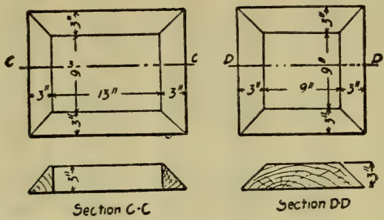


Fig. 22. Forms for constructing openings for the entrance of ducts into concrete vaults.

added and the mixture turned over 3 times with hoes to thoroughly mix the material and dampen every particle of cement. Mortar shall be used within 30 mins. of the time of adding the water. Cement mortar shall be mixed in the proportion of 1 part American Portland cement to 3 parts sand.

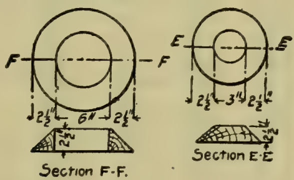


Fig. 23. Forms for constructing openings for the entrance of circular ducts into concrete vaults.

The wages per hour were: Bricklayers, 70 cts.; common laborers, 22 cts.; team and driver, 56 cts. Cost of foreman and timekeeper is included.

TABLE XIX. AVERAGE COST OF BRICK VAULT CONSTRUCTION IN CITIES

Kind of soil	Size No. of vaults	Cost of teaming	Cost of excavating	Cost of placing floor	Cost of laying brick	Cost of placing top	Cost of supervision	Total cost
Sand	1	$2.80	$3.69	$0.94	$11.23	$3.18	$2.87	$24.71
Clay	1	3.28	4.56	0.73	11.39	3.69	3.04	26.69
Hard clay..	1	3.27	5.64	1.04	10.86	3.82	3.16	27.79
Average ..	1	3.12	4.63	0.90	11.16	3.56	3.02	26.39

Kind of soil	Size No. of vaults	Cost of teaming	Cost of excavating	Cost of placing floor	Cost of laying brick	Cost of placing top	Cost of supervision	Total cost
Sand	2	2.97	3.81	1.15	10.71	3.34	3.01	24.99
Clay	2	3.47	4.48	0.92	11.22	3.48	3.41	26.98
Hard clay..	2	3.49	5.52	1.14	11.46	3.67	3.28	28.56
Average ...	2	3.31	4.60	1.07	11.13	3.50	3.23	26.84
Sand	3	2.62	3.85	1.12	12.63	2.55	3.10	25.87
Clay	3	3.64	4.52	1.26	11.47	3.76	3.56	28.31
Hard clay..	3	3.01	5.71	1.34	13.89	3.58	2.93	30.46
Average ...	3	3.09	4.69	1.24	12.66	3.30	3.20	28.18
Sand	4	3.62	4.54	1.82	14.41	4.07	4.12	32.58
Clay	4	4.06	5.78	1.76	14.28	5.83	4.57	36.28
Hard clay..	4	4.85	7.51	2.23	14.12	4.32	4.98	38.01
Average ...	4	4.17	5.94	1.94	14.27	4.74	4.56	35.62
Sand	5	3.48	4.69	2.04	14.47	4.16	4.21	33.05
Clay	5	4.17	5.54	1.93	14.32	5.94	4.86	36.76
Average ...	5	3.83	5.12	1.98	14.39	5.05	4.54	34.91
Sand	6	4.01	4.76	2.33	14.35	4.34	4.51	34.30
Clay	6	3.90	5.71	2.04	14.57	5.66	4.22	36.10
Hard clay..	6	4.46	7.42	2.11	13.86	5.81	4.91	38.57
Average ...	6	4.12	5.96	2.16	14.26	5.27	4.55	36.32
Sand	8	6.27	6.27	3.06	18.27	5.98	5.64	45.49
Clay	8	6.90	8.04	2.87	18.94	6.40	6.87	50.02
Average ...	8	6.59	7.15	2.97	18.60	6.19	6.25	47.75
Sand	9*	2.49	4.01	1.19	11.63	3.43	3.12	26.32
Clay	9*	3.57	4.72	1.21	11.22	3.59	3.44	27.75
Hard clay..	9*	3.68	5.43	1.07	11.56	3.86	3.52	29.12
Average ...	9*	3.40	4.72	1.16	11.47	3.62	3.36	27.73
Sand	9†	3.19	4.27	1.26	12.04	4.01	3.61	28.38
Clay	9†	3.39	4.63	1.19	12.83	4.32	3.97	30.33
Average ...	9†	3.29	4.45	1.23	12.43	4.17	3.79	29.36
Sand	10	7.94	16.43	3.96	26.14	7.27	10.74	72.48
Clay	10	9.12	18.74	4.67	24.82	8.02	12.02	77.39
Hard clay..	10	9.53	22.04	4.09	25.32	7.73	13.81	82.52
Average ...	10	8.86	19.07	4.24	25.43	7.67	12.19	77.46
Clay	11	10.52	26.02	5.34	30.96	8.52	15.11	96.47
Clay	12	9.93	25.64	5.83	32.11	8.36	14.04	95.91
Hard clay..	12	10.14	28.89	5.15	31.07	8.84	14.41	98.50
Average ...	12	10.03	27.27	5.49	31.59	8.60	14.23	97.21

* For 8 ducts or less. † For 9 ducts to 12 ducts.

TABLE XIXA. AVERAGE COST OF CONCRETE VAULT CONSTRUCTION IN CITIES

Kind of soil	Size No. of vaults	Cost of teaming	Cost of excavating	Cost of placing floor	Cost of placing sides	Cost of placing top	Supervision	Total cost
Sand	1	$2.44	$3.79	$1.02	$4.41	$2.44	$2.11	$16.21
Clay	1	3.16	4.38	0.87	4.58	2.83	2.46	18.28
Average	1	2.80	4.08	0.95	4.50	2.63	2.29	17.25
Sand	3	2.78	3.91	1.22	5.79	2.22	2.51	18.43
Clay	3	3.23	4.60	1.14	5.48	3.51	2.87	20.83
Hard clay...	3	3.54	5.83	1.18	5.64	3.42	2.82	22.43
Average	3	3.18	4.78	1.18	5.64	3.05	2.73	20.56

TABLE XX. QUANTITIES AND COST OF MATERIAL AND LABOR REQUIRED IN BRICK VAULTS

	Kind of vault									
Size No.	1	2	3	4	5	6	8	10	11	12
Bags cement for bottom @ .4325	1½	1⅗	1½	2	2	2½	3	4	5	5
Yards sand for bottom @ 1.90	.2222	.2315	.2222	.3055	.2967	.3602	.4459	.5926	.7287	.7162
Yards gravel for bottom @ 1.90	.4444	.4630	.4444	.6111	.5934	.7204	.8917	1.1852	1.4574	1.4324
Cement, sand and gravel for bottom	.7221	.7537	.7221	.9907	.9679	1.1831	1.4487	1.9259	2.3713	2.3338
Yards concrete for bottom	.4814	.5025	.4814	.6605	.6453	.7888	.9630	1.2840	1.5809	1.5559
Cost of concrete for bottom @ 3.98	$1.92	$1.92	$1.92	$2.63	$2.57	$3.14	$3.82	$5.11	$6.29	$6.19
Bags cement for top @ .4325	1.70	1.90	1.80	2.75	2.70	3.25	4.44	6.25	7.75	7.75
Yards sand for top @ 1.90	.1836	.2066	.1942	.3005	.2913	.3530	.4891	.6973	.8474	.8385
Yards gravel for top @ 1.90	.3057	.3439	.3233	.4997	.4850	.5879	.8143	1.1611	1.4111	1.3963
Total cement, sand and gravel for top	.5523	.6209	.5842	.9021	.8763	1.0597	1.4680	2.0899	2.5455	2.5219
Yards concrete for top	.3866	.4347	.4090	.6315	.6135	.7418	1.0260	1.4629	1.7819	1.7654
Cost of concrete for top @ 4.29	$1.66	$1.86	$1.76	$2.71	$2.63	$3.18	$4.40	$6.28	$7.64	$7.57
Bags cement for mortar @ .4325	7.27	7.01	7.69	10.40	10.67	11.33	12.90	14.68	17.24	17.33
Yards sand for mortar @ 1.90	.81	.78	.86	1.16	1.21	1.26	1.44	1.64	1.92	1.93
Total yards sand and cement	1.08	1.04	1.14	1.545	1.61	1.68	1.92	2.18	2.56	2.57
Yards of mortar	.864	.832	.913	1.236	1.286	1.346	1.532	1.743	2.048	2.058
Cost of mortar @ 5.42	$4.68	$4.51	$4.95	$6.70	$6.97	$7.30	$8.30	$9.45	$11.10	$11.15
No. of brick	960	924	1014	1373	1429	1495	1702	1937	2275	2287
Cost of brick @ 8.50	$8.16	$7.85	$8.62	$11.67	$12.15	$12.71	$14.47	$16.46	$19.34	$19.44
Cost of frame and cover	11.74	11.74	11.74	11.74	11.74	11.74	11.74	11.74	11.74	11.74
Total cost of material per vault	28.16	27.88	28.99	35.45	36.06	38.07	42.73	49.04	56.11	56.09
Cost of unloading and distributing material:										
Unloading and distributing cement	$0.24	$0.29	$0.25	$0.35	$0.35	$0.39	$0.46	$0.57	$0.68	$0.69
Cost of unloading and distributing frame and cover	.38	.38	.38	.38	.38	.38	.38	.38	.38	.38
Total cost unloading and distributing material	.62	.67	.63	.73	.73	.77	.84	.95	1.06	1.07
Labor Costs:										
Cost of teaming	3.12	3.31	3.09	4.17	3.83	4.12	6.59	8.86	10.52	10.03
Cost of excavating	4.63	4.60	4.69	5.94	5.12	5.96	7.15	19.07	26.02	27.27
Cost of mixing and placing bottom	.90	1.07	1.24	1.94	1.98	2.16	2.97	4.24	5.34	5.49
Cost of laying brick	11.16	11.13	12.66	14.27	14.39	14.26	18.60	25.43	30.96	31.59
Mixing and placing top and frame	3.56	3.50	3.30	4.74	5.05	5.27	6.19	7.67	8.52	8.60
Supervision and expense	3.02	3.23	3.20	4.56	4.54	4.55	6.25	12.19	15.11	14.23
Total labor cost per vault	26.39	26.84	28.18	35.62	34.91	36.32	47.75	77.46	96.47	97.21
Total cost per vault	$55.17	$55.39	$57.80	$72.80	$71.70	$75.16	$91.32	$127.45	$153.64	$154.37

TABLE XXI. QUANTITIES AND COST OF MATERIALS AND LABOR REQUIRED IN CONCRETE VAULT CONSTRUCTION

Size No. of vault	1	3
Bags cement for bottom @ .4325	1½	1½
Yds. sand for bottom @ 1.90	.2222	.2222
Yds. gravel for bottom @ 1.90	.4444	.4444
Total cement, sand, gravel for bottom	.7221	.7221
Yds. concrete for bottom	.4814	.4814
Cost concrete for bottom @ $3.98	$1.92	$1.92
Bags cement for sides and top @ .4325	7.60	8.02
Yds. sand for sides and top @ 1.90	.8368	.8820
Yds. gravel for sides and top @ 1.90	1.3908	1.4670
Total cement, sand, gravel for sides and top	2.5091	2.6460
Yds. concrete for sides and top	1.7556	1.8518
Cost concrete for sides and top	$7.55	$7.94
Cost frame and cover	11.74	11.74
Total cost material per vault	21.21	21.60
Cost unloading and distributing cement	0.21	0.22
Cost unloading and distributing frame and cover	0 38	0.38
Total cost unloading and distributing material	0.59	0.60
Cost of teaming	2.80	3.18
Cost of excavating	4.08	4.78
Cost of mixing and placing bottom	0.95	1.18
Cost of mixing and placing sides	4.50	5.64
Cost of mixing and placing top and frame	2.63	3.05
Supervision and expense	2.29	2.73
Total labor cost per vault	17.25	20.56
Total cost per vault	39.05	42.76

Construction Costs of Telephone Cable Manholes. Data, July, 1911, gives the following:

BRICK MANHOLE

Concrete Top and Bottom, Barrel Shape

Size	Ducts intersected	Not intersected	Brick Am't No.	Brick Cost
†6 ft. 0 ins. by 8 ft. 0 ins. by 6 ft. 6 ins.	over 18	over 30	1807	$16.26
†4 ft. 0 ins. by 7 ft. 0 ins. by 5 ft. 0 ins.	18	30	1674	1507
‡4 ft. 0 ins. by 6 ft. 0 ins. by 4 ft. 9 ins.	10	20	1261	11.35
‡3 ft. 6 ins. by 6 ft. 0 ins. by 3 ft. 6 ins.	8	12	1171	10.54
‡3 ft. 6 ins. by 5 ft. 0 ins. by 3 ft. 6 ins.	4	8	805	7.25
‡3 ft. 0 ins. by 4 ft. 0 ins. by 4 ft. 0 ins.	2	4	700	6.30
‡2 ft. 6 ins. by 4 ft. 0 ins. by 2 ft. 6 ins.	Handhole		530	4.77

BRICK MANHOLE

Concrete Top and Bottom, Barrel Shape

Size	Cement Am't bbls.	Cement Cost	Sand Am't cu. yds.	Sand Cost	Gravel Am't cu. yds.	Gravel Cost
†6 ft. 0 ins. by 8 ft. 0 ins. by 6 ft. 6 ins.	7.1	$16.69	2.5	$2.25	2.3	$2.05
†4 ft. 0 ins. by 7 ft. 0 ins. by 5 ft. 0 ins.	5.4	12.60	1.8	1.62	1.7	1.53
‡4 ft. 0 ins. by 6 ft. 0 ins. by 4 ft. 9 ins.	3.9	9.16	1.3	1.17	1.0	.90
‡3 ft. 6 ins. by 6 ft. 0 ins. by 3 ft. 6 ins.	3.0	7.05	1.0	.90	0.8	.72
‡3 ft. 6 ins. by 5 ft. 0 ins. by 3 ft. 6 ins.	2.2	5.17	0.8	.72	0.7	.63
‡3 ft. 0 ins. by 4 ft. 0 ins. by 4 ft. 0 ins.	2.0	4.70	0.7	.63	0.6	.54
‡2 ft. 6 ins. by 4 ft. 0 ins. by 2 ft. 6 ins.	1.6	3.76	0.5	.45	0.5	.45

BRICK MANHOLE

Concrete Top and Bottom, Barrel Shape

Size	Miscel.	Labor	Gen'l exp's 10%	Total cost
†6 ft. 0 ins. by 8 ft. 0 ins. by 6 ft. 6 ins.	$28.60	$61.50	$12.74	$140.09
†4 ft. 0 ins. by 7 ft. 0 ins. by 5 ft. 0 ins.	27.75	46.00	10.47	115.13
‡4 ft. 0 ins. by 6 ft. 0 ins. by 4 ft. 9 ins.	26.75	35.00	8.43	92.76
‡3 ft. 6 ins. by 6 ft. 0 ins. by 3 ft. 6 ins.	26.75	34.00	8.00	87.96
‡3 ft. 6 ins. by 5 ft. 0 ins. by 3 ft. 6 ins.	26.75	24.50	6.50	71.52
‡3 ft. 0 ins. by 4 ft. 0 ins. by 4 ft. 0 ins.	26.50	20.00	5.87	64.54
‡2 ft. 6 ins. by 4 ft. 0 ins. by 2 ft. 6 ins.	25.75	18.00	5.32	58.50

* Inter-Mountain Data
† Bottom 6 ins. thick, top 8 ins. thick.
‡ Bottom 4 ins. thick, top 6 ins. thick

CONCRETE MANHOLE

Barrel Shape

Size	Ducts intersected	Not intersected	Cement Am't bbls.	Cost
†6 ft. 0 ins. by 8 ft. 0 ins. by 6 ft. 0 ins.	over 18	over 30	9.6	$22.80
†4 ft. 0 ins. by 7 ft. 0 ins. by 5 ft. 0 ins.	18	30	7.2	16.90
‡4 ft. 0 ins. by 6 ft. 0 ins. by 4 ft. 9 ins.	10	20	4.7	9.05
‡3 ft. 6 ins. by 6 ft. 0 ins. by 3 ft. 6 ins.	8	12	3.3	7.75
§3 ft. 6 ins. by 5 ft. 0 ins. by 3 ft. 6 ins.	4	8	2.4	5.65
§3 ft. 0 ins. by 4 ft. 0 ins. by 4 ft. 0 ins.	2	4	2.8	6.60
§2 ft. 6 ins. by 4 ft. 0 ins. by 2 ft. 6 ins.	Handole		1.6	3.76

CONCRETE MANHOLE

Barrel Shape

Size	Sand Am't cu. yds.	Sand Cost	Gravel Am't cu. yds.	Gravel Cost
†6 ft. 0 ins. by 8 ft. 0 ins. by 6 ft. 6 ins. ...	4.0	$3.60	6.7	$6.03
†4 ft. 0 ins. by 7 ft. 0 ins. by 5 ft. 0 ins. ...	3.1	2.80	5.1	4.50
‡4 ft. 0 ins. by 6 ft. 0 ins. by 4 ft. 9 ins. ...	2.0	1.80	3.4	3.05
‡3 ft. 6 ins. by 6 ft. 0 ins. by 3 ft. 6 ins. ...	1.5	1.35	2.3	2.05
§3 ft. 6 ins. by 5 ft. 0 ins. by 3 ft. 6 ins. ...	1.0	.90	1.7	1.55
§3 ft. 0 ins. by 4 ft. 0 ins. by 4 ft. 0 ins. ...	1.2	1.08	2.0	1.80
§2 ft. 6 ins. by 4 ft. 0 ins. by 2 ft. 6 ins. ...	0.7	.63	1.1	1.00

CONCRETE MANHOLE

Barrel Shape

Size	Miscel.	Labor	Gen'l expen's	Total cost
†6 ft. 0 ins. by 8 ft. 0 ins. by 6 ft. 6 ins.	$29.70	$63.00	$12.35	$135.85
†4 ft. 0 ins. by 7 ft. 0 ins. by 5 ft. 0 ins.	28.30	41.00	9.35	102.85
‡4 ft. 0 ins. by 6 ft. 0 ins. by 4 ft. 9 ins.	27.19	31.00	7.21	79.30
‡3 ft. 6 ins. by 6 ft. 0 ins. by 3 ft. 6 ins.	27.15	24.00	6.23	68.53
§3 ft. 6 ins. by 5 ft. 0 ins. by 3 ft. 6 ins.	27.05	19.00	5.42	59.57
§3 ft. 0 ins. by 4 ft. 0 ins. by 4 ft. 0 ins.	26.95	20.00	5.64	62.07
§2 ft. 6 ins. by 4 ft. 0 ins. by 2 ft. 6 ins.	26.20	14.00	4.56	50.15

Miscellaneous, includes all the reinforcing wire and steel, the frame and cover, lumber, and other small items.

Labor, based on $2.25 per day for laborers and $3.00 per day for foremen.
Concrete, mixture: 1:3:5:
Brick, $9.00 per thousand.
Cement, $2.25 per barrel.
Sand and Gravel, $.90 per cubic yard.
Labor for laying brick, $12.00 per thousand.

* Inter-Mountain Data.
† 6 in. Bottom, 8 in. Top, 8 in. Walls.
‡ 4 in. Bottom, 6 in. Top, 6 in. Walls.
§ 4 in. Bottom, 6 in. Top, 5 in. Walls.

Cost of Brick Manholes for Electric Conduit. The following, taken from Data, April, 1913, was compiled from data collected by a large central station located in the Middle West.

Size, ft.	Street unimp.	Cedar paving	Ced. on 6-in. conc.	Granite paving	Gran. on paving	Macadam	Asphalt
2 by 3 by 3	$31.04	$32.18	$32.94	$32.94	$34.83	$31.92	$38.63
3 by 3 by 4	41.12	42.52	43.46	43.46	45.80	42.21	50.48
3 by 4 by 4	47.54	49.21	50.32	50.32	53.10	48.84	58.67
4 by 4 by 4	53.47	55.45	56.78	56.78	60.08	55.01	66.70
4 by 5 by 5	64.75	67.05	68.58	68.58	72.44	66.54	80.08
5 by 5 by 5	109.06	111.67	113.50	113.50	117.94	111.13	126.82
6 by 6 by 6	133.13	136.57	138.87	138.87	144.60	135.81	156.08
6 by 7 by 6	142.76	146.62	149.19	149.16	155.63	145.76	168.50
7 by 7 by 7	160.06	164.38	167.27	167.27	174.47	163.42	188.89
8 by 8 by 8	189.16	194.65	198.19	198.19	207.03	193.48	224.72

Cost of Brick Manhole for Telephone Cables, Chicago. The costs given below, published in Data, June, 1911, do not include supervision or other overhead expenses.

Dimensions: 3 ft. by 5 ft. by 4 ft. 6 ins. high. Brick walls, concrete top and floor

Materials:		
1100 brick at $8.00 per M	$ 8.80	
14 bags of cement at 41c. per bag	5.75	
1¼ cu. yds. sand at $1.75 per cu. yd	2.19	
1¼ cu. yds. gravel at $1.65 per cu. yd	2.06	
110 ft. hemlock lumber at $22.50 per M. ft	2.48	
1 frame and cover	12.00	
2 lbs. nails at 2½ cts. per lb.	.05	
6 nipples at 4½ cts. each	.27	
Wooden form for concrete top	1.50	
Total material		$35.10
Labor and Teaming:		
Excavating	4.00	
Backfilling	.75	
Bricklaying — 1100 brick at $10.00 per M	11.00	
Labor mixing and placing concrete	2.50	
Hauling away earth	3.50	
Total labor and teaming		21.75
Total cost of manhole		$56.85
Cost of sewer connection where required		20.00

Cost of Constructing 15 Brick Vaults for Underground Conduit. Mr. Clarence Mayer in Engineering and Contracting, Oct. 28, 1908,

gives in somewhat more detail the labor costs on brick vaults. (Fig. 12.) The costs show separately the costs of placing floors and tops and also the cost of board and car fare. They also show work done in paved streets. The paving was cedar blocks in clay and the costs given include the cost of replacing same.

TABLE XXII. LABOR COST OF CONSTRUCTING 15 BRICK VAULTS 3 FT. 6 INS. x 4 FT. 6 INS. x 4 FT. 6 INS. FOR UNDERGROUND CONDUIT

	Cost of teaming	Cost of excavating	Cost of placing floor	Cost of laying brick	Cost of placing top	Cost of supervision	Board	Car fare	Total cost
Min.	$2.85	$4.05	$0.65	$11.50	$4.60	$2.65	$0.15	$0.03	$27.80
Av.	3.04	4.33	0.79	12.35	5.16	2.89	0.24	0.05	28.85
Max.	3.30	5.00	0.90	15.00	5.80	3.10	0.35	0.08	30.41

Main Underground Cable. Mayer's Telephone Construction says: Underground cable is of the following kinds: 50 pr., 22 ga. and 19 ga.; 100 pr., 22 ga. and 19 ga.; 200 pr., 22 ga. and 19 ga.; 300 pr., 22 ga. and 19 ga.; 400 pr., 22 ga.; 600 pr., 22 ga.; 150 pr., 16 ga.; toll cable, and 120 pr., .5-14 ga. and .5-16 ga. toll cable. The specifications for underground cable work are as follows:

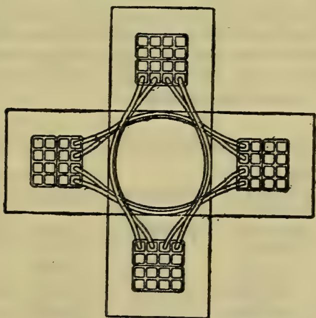


Fig. 24. Diagrams showing method of passing cable through vaults.

The cable may be pulled by capstan, by winch, by horse power or by hand, at a speed not to exceed 50 ft. per minute. In setting up, the reel should be as nearly in line with the duct as possible and ahead of the vault rather than back of it, so that the cable will feed from the top of the reel. To the end of the No. 12 steel wire which is pulled in when rodding the duct, shall be fastened a steel rope which in turn shall be fastened to the cable by means of a cable clamp, wire hitch or other approved method. Skids and

sheaves shall be set up as nearly as possible in a straight line from the mouth of the duct. The cable should be fed in at a uniform speed and the armor carefully inspected. Where the cable is 2 ins. or more in diameter, the ducts should be swabbed with soapstone, mica or graphite, except in the case of short straight runs. Cable in passing through vaults shall be divided so that cable entering the vault on either side of the center of the vault shall be carried around that side of the vault to the duct where it leaves vaults again, as shown in Fig. 24.

The rates of wages on which the following costs of underground cable work are based are as follows:

Station gangs:		
Foremen, per month	$90.00 to	$100.00
Timekeeper, per 8-hour day	2.25 to	2.50
Linemen, per 8-hour day	2.95 to	3.25
Combination men, per 8-hour day	2.25 to	2.50
Groundmen, per 8-hour day	2.00 to	2.15
Teams, per 8-hour day	4.00 to	4.50
Floating gangs:		
Foremen, per month and board	65.00 to	75.00
Timekeeper, per 8-hour day and board	1.25 to	1.40
Linemen, per 8-hour day and board	1.80 to	2.00
Combination men, per 8-hour day and board	1.25 to	1.40
Groundmen, per 8-hour day and board	1.00	
Teams, per 8-hour day and board	3.00 to	4.00

From 50 to 75 cts. per day are allowed for board of team and $1 per day, including Sundays, is allowed for board of each man. In the cost data given, the rate for men in floating gangs is found by dividing the board per month, $30 or $31, by the number of working days, 26 or 27, and adding the amount to their rate per day. Mistakes in construction such as digging a hole in the wrong location are not included in these averages.

TABLE XXIII. COST OF UNDERGROUND CABLE (MAIN)

	Teaming and labor in hauling	Rodding	Pulling	Supervision and expense	Average cost per foot
50 Pr.—19 Ga.	$0.0048	$0.0034	$0.0061	$0.0017	$0.0161
100 Pr.—22 Ga.	0.0042	0.0037	0.0065	0.0018	0.0162
100 Pr.—19 Ga.	0.0051	0.0039	0.0062	0.0019	0.0172
200 Pr.—22 Ga.	0.0057	0.0036	0.0067	0.0015	0.0175
200 Pr.—19 Ga.	0.0061	0.0031	0.0071	0.0021	0.0184
300 Pr.—22 Ga.	0.0066	0.0036	0.0097	0.0018	0.0217
300 Pr.—19 Ga.	0.0073	0.0030	0.0093	0.0024	0.0220
150 Pr.—16 Ga. Toll Cable	0.0101	0.0058	0.0147	0.0043	0.0349
120 Pr.—½–14 Ga. and ½–16 Ga. Toll Cable	0.0122	0.0068	0.0158	0.0048	0.0396

NOTE: The weight of a reel of 120 Pr.—½–14 Ga. and ½–16 Ga. averages between 3¾ and 5 tons. The cable grip shown in Fig. 26 was used on some jobs in pulling in the cable. It reduces the cost, as it may be connected and removed instantly, whereas a wire hitch takes some time to attach and remove. It also is superior to a wire hitch because it does not injure the cable and will not pull off.

TABLE XXIV. COST OF UNDERGROUND CABLE (LATERAL)

	Teaming and labor in hauling per foot	Pulling per foot	Supervision and expense per foot	Average cost per foot	Average length of laterals in feet	Average cost per lateral
25 Pr.— 22 Ga...	$0.0044	$0.0112	$0.0029	$0.0185	117	$2.17
50 Pr.— 22 Ga...	0.0063	0.0198	0.0042	0.0303	132	4.01
50 Pr.— 19 Ga...	0.0071	0.0226	0.0062	0.0359	123	4.42
100 Pr.— 22 Ga...	0.0068	0.0220	0.0059	0.0347	126	4.36
100 Pr.— 19 Ga...	0.0111	0.0316	0.0064	0.0491	115	5.64
200 Pr.— 22 Ga...	0.0109	0.0310	0.0061	0.0480	112	5.39
200 Pr.— 19 Ga...	0.0138	0.0354	0.0076	0.0568	117	6.62

NOTE: 25 Pr.— 22 Ga. costs much less to install than other cable, as it is always pulled in by hand, and its small diameter and light weight make it easily handled.

Lateral Underground Cable. Lateral underground cable is of the following kinds: 25 pr., 22 ga. and 19 ga.; 50 pr., 22 ga. and 19 ga.; 100 pr., 22 ga. and 19 ga., and 200 pr., 22 ga. and 19 ga. The specifications for this work are as follows:

Lateral cable shall be set up and pulled in the same manner as main cable. Where the cable is 1 in. or over in diameter, the duct should be swabbed with soapstone, mica or graphite, except in the case of short, straight laterals, 100 ft. or less.

Rodding Underground Cable. The duct in which cable is to be placed shall first be rodded. To the end rod shall be attached a length of No. 12 steel wire, which shall be used to pull into the duct the steel rope, used in pulling the cable.

TABLE XXV. COST OF RODDING

	Teaming and labor in hauling	Rodding	Supervision and expense	Average cost per foot
City	$0.0010	$0.0036	$0.0016	$0.0062
County	0.0018	0.0061	0.0019	0.0098

Table XXVI shows the labor cost in detail of pulling in 120 pr. one-half 14-gage and one-half 16-gage toll cable. The expense of hauling reels was large, as the distance from the freight depot averaged 3 miles, the roads were deep in clay mud, and on account of their great weight a special team and wagon at $7 per day was used to haul the reels. The expense of pumping water was high on account of the vaults being full of water. In one section of conduit, cable was pulled in twice, as the first cable had flaws in the armor. The cable was pulled in by horsepower.

Removing Underground Cable. All underground cable to be removed must be cut at each splice and have the ends of the sections sealed, before they are removed from the duct, unless the cable is to

TABLE XXVI. COST OF PULLING UNDERGROUND CABLE (MAIN).

120 Pr., ½–14 Ga. and ½–16 Ga.

No. ft. pulled	Cost of pulling	No. men used in pulling	Cost of rodding	Cost of pumping water	No. sections pulled	Cost of pulling, rodding and pumping
18,992	$333.40	93	$90.90	$79.60	38	$503.90
	Per ft.	Per day	Per ft.	Per ft.	Per day	Per ft.
Average	$.0175	6 1-5	$.0048	$.0042	2 8-15	$.0265

	Hauling Reels			Returning Reels		
No. reels hauled	Cost of hauling	No. men used in hauling	No. reels returned	Cost of returning	No. men used in returning	Total cost of all work
39	$211.60	67	39	$65.10	23	$780.60
	Per reel,	No. men per reel,		Per reel,	No. men per reel.	
Average	$5.40	2		$1.67	23–39	$.0411

TABLE XXVII. COST OF REMOVING UNDERGROUND CABLE (JUNKED)

	Teaming and labor in hauling	Removing	Supervision and expense	Average cost per foot
50 Pr.—22 Ga.....	$0.0038	$0.0072	$0.0019	$0.0129
50 Pr.—19 Ga.....	0.0043	0.0079	0.0021	0.0143
100 Pr.—22 Ga.....	0.0041	0.0075	0.0017	0.0133
100 Pr.—19 Ga.....	0.0054	0.0083	0.0024	0.0161
200 Pr.—22 Ga.....	0.0056	0.0086	0.0019	0.0161
200 Pr.—19 Ga.....	0.0061	0.0094	0.0026	0.0181
300 Pr.—22 Ga.....	0.0073	0.0108	0.0029	0.0210

TABLE XXVIII. COST OF REMOVING UNDERGROUND CABLE (RECOVERED)

	Teaming and labor in hauling	Removing	Supervision and expense	Average cost per foot
25 Pr.—22 Ga.....	$0.0034	$0.0073	$0.0018	$0.0125
50 Pr.—22 Ga.....	0.0041	0.0079	0.0017	0.0137
50 Pr—19 Ga.....	0.0044	0.0084	0.0022	0.0150
100 Pr.—22 Ga.....	0.0050	0.0086	0.0023	0.0159
100 Pr.—19 Ga.....	0.0053	0.0093	0.0026	0.0172
200 Pr.—22 Ga.....	0.0058	0.0089	0.0022	0.0169
200 Pr.—19 Ga.....	0.0064	0.0099	0.0028	0.0191
300 Pr.—22 Ga.....	0.0077	0.0115	0.0033	0.0225

be junked. The apparatus is placed at the vault from which the cable is to be pulled. In place of the steel rope used in pulling in, a manila rope is used on account of its greater flexibility. The vault skids and sheaves are placed in the same manner as for pulling in cable, and the manila rope passed over them in the usual manner. To the end of the rope is attached a servage strap made of manila strand about 1 in. in diameter. This strap is

placed on the cable in the form of a noose which grips the cable when pulled one way, but may be pushed along the cable in the reverse direction. The strap is then slipped around the end of the cable as close to the duct as possible, and power applied to the pulling line. After the cable has been moved a foot or two the rope is slackened off and the noose is again pushed forward against the duct. This process is known as "luffing." The "luffing" is continued until the cable is removed from the duct. As the cable is pulled out, if it is to be recovered, it is reeled upon a reel placed back of the manhole, so as to avoid unnecessary sharp turns. If it is to be junked the cable is usually cut with an axe into 5 or 6 ft. lengths as it is being pulled out.

Method and Cost of Cable Splicing. Of all outside construction the most delicate work is cable splicing, and it requires the most skilled and careful labor. The careless removal of the insulation from conductors has been known to cause crosses which cost hundreds of dollars to locate and clear. A splice when not properly made is always a source of "trouble cases" which are difficult to locate and expensive to clear; but even the cost of locating and clearing is small in comparison with the loss of revenue and the annoyance to subscribers caused by the interruption of service, especially when a main cable is in trouble. Above all things, good splicing requires conscientious work, and on the personnel of the men depends the quality of the splice. Cheap splicing is not generally good splicing; therefore in estimating the cost of splicing, no attempt should be made to force quick work, which is nearly always expensive in the end.

The organization of splicer gangs is somewhat different from line gangs; the gangs being composed of a head splicer, one or two splicers, and an equal number of helpers. Each gang is assigned to a district and is stationed in the principal town in the district. When necessary a gang is increased by drawing from other gangs, and all men receive board when working outside of the town in which they are stationed. The head splicer usually splices or tests out when the gang is small, little supervision being necessary.

A great deal of overtime is worked because of most splices which cause interruption of the service being made at night and also on account of splices being often worked on until finished. This sometimes makes a splicer's wages per one-half month between $60 and $100 dollars.

Systematizing the costs of cable splicing is more difficult than in any other branch of telephone construction; first, because of the general confusion in the names of the different splices, and second, because of the endless combinations in splicing. In order to avoid confusion, a leg of a cable box will be referred to as a cable and two sections of a cable not already spliced will be called two cables; thus if two sections of a 100-pr. cable are to be spliced they will be referred to as two 100-pr. cables. For our purposes the splicing of conductors will be used to indicate the kind of splice, and splices will be referred to as follows.

Straight Splices. (1) When all the conductors of two cables are

spliced together, each joint of conductors being composed of two wires; (2) when the conductors of one cable are spliced into a cable containing a larger number of conductors, part of which are left "dead," each joint of conductors being composed of two wires; and (3) where either part or all of the conductors of two or more cables are spliced into part or all of the conductors of another cable, each joint of conductors being composed of two wires and the conductors not spliced being left "dead."

Bridge Splices. (1) When all the conductors of three or more cables are spliced together, each joint of conductors being composed of the same number of wires; (2) when all the conductors of a cable are spliced into a cable composed of one-half, one-quarter, etc., the number of conductors, each joint of conductors being composed of like number of wires.

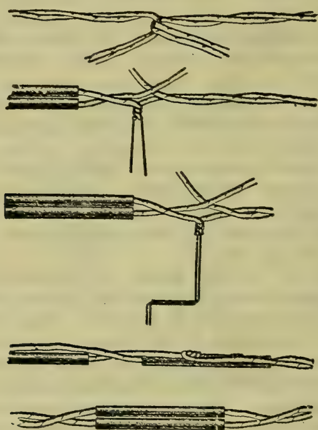


Fig. 25. Sequence of operations in making straight splices.

Straight-Bridge Splices. When some of the conductors of a cable are spliced, as described under "Straight Splice" and some as described under "Bridge Splice."

There are endless combinations in splicing, as for example, into a 100-pr. cable may be spliced a 10, 15, 25, 50 or 100 pr. cable, etc., or a 10, 15, 25 and 50-pr. cable, etc. Also the splice may be straight, bridge, straight-bridge or change of count; it may be tagged or not tagged. In estimating it is not necessary to have data on every possible splice. If data showing the average cost of common and usual splices is accessible a very close estimate of any splice may be made.

For construction details and instructions for making the various kinds of splices mentioned above the reader is referred to Mayer's Telephone Construction from which these data and costs are taken:

Cable splicing costs are based on the following rate of wages:

	Per 8-hour day
Head splicers	\$3.40 to \$3.70
Splicers	3.00 to 3.20
Helpers	1.75 to 2.00
Rigs (usually single)	2.50 to 3.00

Time and one-half is paid for overtime. There being practically no difference between the cost of splicing 19 gage and 22 gage cables they are not separated in the following cost data. The costs of making several splices of the same kind and size have been found to vary very little. Except when the splicing is done by splicers who have worked all night, usually splices of the same kind and size will not vary more than 10 per cent.

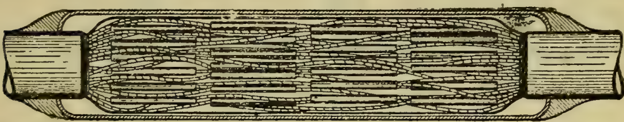


Fig. 26. Completed cable splices.

The cost of splicing into working cable is kept separate on account of being more expensive than splicing into other cable. The difference is caused by it being necessary to test and tag all cables spliced, the care used to prevent unnecessary interruption of service and also because the splice is often worked on after regular hours for which splicers are paid time and one-half.

The cost of blowing the joint of a working cable and the cost of cutting the sheath off of cables in preparing for a splice, are about equal.

TABLE XXIX. COST OF STRAIGHT SPLICES, UNDERGROUND

(Cost of splicing 60 prs. from each of two 120 pr. ½–14 gage and ½–16 gage toll cables into a 120 pr. 18 gage cable terminating in a loading pot, and splicing the balance straight through.)

Part of cable spliced straight through	Teaming	Pumping	Framing	Testing	Splicing	Wiping joints	Supervision and expense	Average cost per splice
14 Gage	\$1.04	\$0.62	\$1.68	\$1.80	\$8.69	\$1.82	\$6.47	\$22.12
16 Gage	1.01	0.64	1.64	1.86	8.88	1.79	6.52	22.34

Note: This class of work is generally done in the country. The supervision of a head splicer and board for the gang make the cost of "Supervision and Expense" high.

TABLE XXX. COST OF STRAIGHT SPLICES, UNDERGROUND, NOT TAGGED

Number and size of cables spliced	Teaming	Pumping	Framing	Splicing	Wiping joints	Supervision and expense	Average cost per splice
2– 50 Pr.	$0.46	$0.53	$0.49	$0.80	$0.45	$0.60	$3.33
2–100 Pr.	0.59	0.56	0.60	1.42	0.49	0.86	4 52
2–200 Pr.	0.59	0.58	0.87	2.86	0.57	1.38	6.85
2–300 Pr.	0.61	0.55	0.91	3.67	0.61	1.59	8.04
1–25 Pr. into 1–50 Pr., 25 Prs. Left Dead.	0.40	0.42	0.44	.065	0.42	0.54	2.87
1–50 Pr. into 1–100 Pr., 50 Prs. Left Dead.	0.52	0.51	0.52	0.84	0.49	0.72	3.60
1–100 Pr. into 1–200 Prs., 100 Prs. Left Dead	0.58	0.57	0.76	1.51	0.54	0.94	4.90

TABLE XXXI. COST OF STRAIGHT SPLICES, UNDERGROUND, TAGGED

Number and size of cables spliced	Teaming	Pumping	Framing	Testing and tagging	Splicing	Wiping joints	Supervision and expense	Average cost per splice
2– 50 Pr	$0.42	$0.49	$0.51	$0.98	$0.78	$0.42	$0.64	$4.24
2–100 Pr.	0.56	0.54	0.62	1.58	1.37	0.51	1.11	6.29
2–200 Pr.	0.59	0.58	0.85	2.80	2.78	0.60	1.72	9.92
2–300 Pr.	0.60	0.57	0.89	4.06	3.69	0.62	2.06	12.49
2–150 Pr. 16 Gauge Toll Cable	0.96	0.61	0.92	1.56	2.37	0.63	3.17	10.22
2–120 Pr. ½–14 and ½–16 Ga. Toll Cable	0.94	0.60	0.91	1.39	1.96	0.66	2.89	9.35
1–50 Pr. into 1–100 Pr., 50 Prs. Left Dead	0.49	0.50	0.54	1.07	0.84	0.59	0.71	4.74
2–50 Pr. into 1–100 Pr.	0.57	0.54	0.83	1.62	1.44	0.67	1.16	6.83

NOTE: Toll cable is always tested for crosses, grounds and insulation, but not tagged. Teaming and supervision and expense are higher for toll cable than for other cable on account of the work being done in the country.

TABLE XXXII. COST OF BRIDGE SPLICES, UNDERGROUND, NOT TAGGED

Number and size of cables spliced	Teaming	Pumping	Framing	Splicing	Wiping joints	Supervision and expense	Average cost per splice
3– 50 Pr.	$0.44	$0.50	$0.61	$1.56	$0.65	$0.78	$4.54
3–100 Pr.	0.53	0.47	0.76	2.78	0.72	1.18	6.44
3–200 Pr.	0.58	0.53	0.91	5.37	0.89	1.74	10.02

TABLE XXXIII. COST OF BRIDGE SPLICES, UNDERGROUND, TAGGED

Number and size of cables spliced	Teaming	Pumping	Framing	Testing and tagging	Splicing	Wiping joints	Supervision and expense	Average cost per splice
3– 50 Pr. ...	$0.46	$0.48	$0.62	$1.52	$1.53	$0.66	$1.27	$6.54
3–100 Pr. ...	0.42	0.52	0.74	2.39	2.52	0.70	1.58	8.87
3–200 Pr. ...	0.63	0.52	0.87	3.72	4.89	0.82	2.02	13.47

TABLE XXXIV. COST OF BRIDGE SPLICES, UNDERGROUND, ONTO WORKING CABLE

Number and size of cables spliced	Teaming	Pumping	Framing	Testing and tagging	Splicing	Wiping joints	Supervision and expense	Average cost per splice
1–50 Pr. Bridged onto a Splice of 2–50 Pr.	$0.69	$0.53	$0.68	$2.26	$0.97	$0.76	$1.27	$7.16
1–100 Pr. Bridged onto a Splice of 2–100 Pr.	0.75	0.49	0.73	3.79	1.82	0.82	1.83	10.23
1–200 Pr. Bridged onto a Splice of 2–200 Pr.	0.69	0.61	0.86	5.82	3.68	0.81	2.26	14.73

TABLE XXXV. COST OF STRAIGHT-BRIDGE SPLICES, UNDERGROUND, NOT TAGGED

No. and size of branch cables spliced into main cables	Number and size of main cables spliced	Teaming	Pumping	Framing	Splicing	Wiping joints	Supervision and expense	Average cost per splice
1– 25 Pr.	2– 50 Pr.	$0.38	$0.46	$0.56	$1.24	$0.62	$0.74	$4.00
1– 25 Pr.	2–100 Pr.	0.52	0.51	0.70	1.83	0.71	1.06	5.33
1– 25 Pr.	2–200 Pr.	0.46	0.47	0.78	3.32	0.78	1.48	7.29
1– 50 Pr.	2–100 Pr.	0.54	0.54	0.71	2.10	0.72	1.14	5.75
1– 50 Pr.	2–200 Pr.	0.47	0.59	0.82	3.58	0.84	1.60	7.90
1– 50 Pr.	2–300 Pr.	0.60	0.52	0.91	5.95	0.88	1.68	10.54
1–100 Pr.	2–200 Pr.	0.64	0.57	0.84	4.03	0.82	1.61	8.51
1–100 Pr.	2–300 Pr.	0.57	0.55	0.98	6.21	0.91	1.74	10.96
1–200 Pr.	2–300 Pr.	0.59	0.61	1.06	6.86	0.84	2.05	12.01

TABLE XXXVI. COST OF STRAIGHT-BRIDGE SPLICES, UNDERGROUND, TAGGED

No. and size of branch cables spliced into main cables	Number and size of main cables spliced	Teaming	Pumping	Framing	Testing and tagging	Splicing	Wiping joints	Supervision and expense	Average cost per splice
1– 25 Pr.	2– 50 Pr.	$0.41	$0.49	$0.59	$1.13	$1.03	$0.56	$1.02	$5.23
1– 25 Pr.	2–100 Pr.	0.47	0.53	0.68	2.01	1.69	0.64	1.30	7.32
1– 25 Pr.	2–200 Pr.	0.51	0.51	0.79	3.16	2.89	0.67	1.71	10.24
1– 50 Pr.	2–100 Pr.	0.50	0.47	0.73	2.18	1.82	0.62	1.36	7.68
1– 50 Pr.	2–200 Pr.	0.60	0.54	0.84	3.37	3.16	0.69	1.79	10 99
1– 50 Pr.	2–300 Pr.	0.57	0.62	0.94	4.18	4.99	0.78	2.28	14.36
1–100 Pr.	2–200 Pr.	0.54	0.56	0.83	3.67	3.61	0 72	1.84	11.77
1–100 Pr.	2–300 Pr.	0.62	0.61	1.01	4.49	5.48	0.66	2.41	15.28
1–200 Pr.	2–300 Pr.	0.59	0.64	0.99	4.87	6.49	0.71	2.63	16.92
1– 25 Pr. 1– 50 Pr.	2–100 Pr.	0.53	0.59	0.82	2.39	2.16	0.83	1.50	8.82
1– 25 Pr. 1– 50 Pr.	2–200 Pr.	0.56	0.59	1.03	3.48	3.47	0.91	1.87	11.91
2– 25 Pr.	2–100 Pr.	0.49	0.56	0.75	2.26	1.96	0.87	1.41	8.30
2– 50 Pr.	2–200 Pr.	0.53	0.61	0.97	3.62	3.76	0.91	1.92	12.32
1– 50 Pr. 1–100 Pr.	2–200 Pr.	0.61	0.66	1.14	4.04	4.54	0.89	2.20	14.08
1– 50 Pr. 1–100 Pr.	2–300 Pr.	0.64	0.64	1.16	4.68	5.88	0.94	2.68	16.62
1– 50 Pr. 2–100 Pr.	2–300 Pr.	0.69	0.68	1.37	5.15	6.86	1.17	2.91	18.83
1– 25 Pr. 1– 50 Pr. 1–100 Pr.	2–200 Pr.	0.62	0.73	1.26	3.90	4.07	1.10	2.18	13.86

TABLE XXXVII. COST OF STRAIGHT-BRIDGE SPLICES, UNDERGROUND, ONTO WORKING CABLES

No. and size of branch cables spliced into main cable	Size of main cable	Teaming	Pumping	Framing	Testing and tagging	Splicing	Wiping joints	Supervision and expense	Average cost per splice
1– 25 Pr.	50 Pr.	$0.46	$0.52	$0.53	$1.36	$0.72	$0.64	$1.08	$5.31
1– 25 Pr.	100 Pr.	0.51	0.47	0.57	2.74	0.80	0.63	1.29	7.01
1– 25 Pr.	200 Pr.	0.47	0.50	0.64	3.74	0.87	0.71	1.44	8.37
1– 50 Pr.	100 Pr.	0.44	0.53	0.55	3.06	1.18	0.61	1.39	7.76
1– 50 Pr.	200 Pr.	0.52	0.49	0.67	4.19	1.23	0.68	1.57	9.35
1– 50 Pr.	300 Pr.	0.54	0.61	0.69	5.30	1.31	0.79	1.80	11.04
1–100 Pr.	200 Pr.	0.51	0.58	0.74	4.70	2.06	0.80	1.76	11.15
1–100 Pr.	300 Pr.	0.62	0.51	0.72	5.82	2.14	0.74	1.99	12.54
1–200 Pr.	300 Pr.	0.57	0.67	0.68	7.06	3.70	0.82	2.52	16.02
1– 25 Pr. 1– 50 Pr.	200 Pr.	0.54	0.62	0.89	4.33	1.84	0.96	1.63	10.81
2–50 Pr.									
1– 25 Pr.	200 Pr.	0.63	0.53	1.01	4.17	2.16	1.01	1.91	11.42
1– 50 Pr.	300 Pr.	0.58	0.59	0.96	5.51	1.97	0.97	2.02	12.60

NOTE: All the data on straight-bridge splices, both aerial and

TABLE XXXIX. COST OF CHANGING COUNTS, UNDERGROUND, ON WORKING CABLE, TAGGED

No. and size of branch cables	Size of main cable	No. of pairs spliced straight	No. of pairs bridged	Teaming	Pumping	Framing	Testing and tagging	Splicing	Wiping joints	Supervision and expense	Average cost per splice
1– 25 Pr.	100 Pr.	...	25	$0.63	$0.57	$1.06	$2.74	$1.44	$.67	$1.66	$8.77
1– 25 Pr.	200 Pr.	...	25	0.74	0.62	1.18	3.79	1.63	0.64	1.79	10.39
1– 50 Pr.	100 Pr.	...	50	0.83	0.71	1.34	3.11	2.99	0.71	1.86	11.55
1– 50 Pr.	200 Pr.	...	50	0.72	0.68	1.43	4.12	3.18	0.69	2.08	12.90
1–100 Pr.	200 Pr.	...	100	0.84	0.61	2.56	4.88	5.21	0.73	2.57	17.40
1–100 Pr.	300 Pr.	...	100	0.79	0.52	2.70	5.74	5.53	0.70	2.91	18.80

TABLE XL. COST OF UNDERGROUND CUTS

No. and size of branch cables	Size of cables off of which branches were cut	Size of cables into which branches were spliced	No. of pairs spliced straight	No. of pairs bridged	Teaming	Pumping	Framing	Testing and tagging	Splicing	Wiping joints	Supervision and expense	Average cost per splice
1– 25 Pr.	100 Pr.	100 Pr.	...	25	$0.66	$0.51	$1.32	$2.82	$1.91	$1.01	$1.67	$9.90
1– 25 Pr.	200 Pr.	200 Pr.	...	25	0.70	0.54	1.37	3.90	2.04	0.94	1.83	11.32
1– 50 Pr.	100 Pr.	100 Pr.	...	50	0.62	0.47	1.59	3.12	3.64	1.08	1.94	12.46
1– 50 Pr.	200 Pr.	200 Pr.	...	50	0.72	0.62	1.71	4.03	3.72	0.96	2.02	13.78
1–100 Pr.	200 Pr.	300 Pr.	...	100	0.78	0.68	2.67	4.80	5.53	1.03	2.66	18.15
1–100 Pr.	300 Pr.	300 Pr.	...	100	0.61	0.56	2.93	5.84	5.76	1.01	2.79	19.50
1–200 Pr.	200 Pr.	200 Pr.	...	200	0.73	0.59	3.31	5.89	8.13	1.08	3.24	22.97
2– 25 Pr.	200 Pr.	200 Pr.	...	50	0.81	0.54	2.14	4.09	3.96	1.33	2.23	15.10
2– 50 Pr.	200 Pr.	200 Pr.	...	100	0.83	0.63	2.78	4.74	5.73	1.49	2.58	18.78

NOTE. Cable off of which the branches are cut is generally a working cable.

underground, is based on splicing branch cables on separate counts. It makes little difference in the cost, however, whether the branches are spliced on the same or separate counts. In all the data on straight-bridge splices the two sections of the continuous cable, when not already spliced, are entered in the column, "Number and Size of Main Cables Spliced," as 2–25 Pr., 2–50 Pr., etc. When the cable is already spliced, as in the data under "Working Cables," it is referred to as 25 Pr., 50 Pr., etc.

TABLE XXXVIII. COST OF CHANGING COUNTS, UNDERGROUND, NOT TAGGED

No. and size of branch cables	Size of main cable	No. of pairs spliced straight	No. of pairs bridged†	Teaming	Pumping	Framing	Splicing	Wiping joints	Supervision and expense	Average cost per splice
1–25 Pr.*	100 Pr.	25	..	$0.59	$0.43	$1.11	$1.03	$0.58	$0.96	$4.70
1–25 Pr.	200 Pr.	..	25	0.53	0.52	1.22	1.28	0.67	1.07	5.29
1–50 Pr.	200 Pr.	..	50	0.67	0.49	1.62	1.91	0.69	1.30	6.68

† These splices were made onto pairs left dead.
* The main cable ended at the splice.

In making a change of count or a cut it is often necessary to lengthen the conductors by splicing on a piece of wire of the same gage. This adds considerably to the cost of splicing conductors together.

Pulling and Splicing Cables. The following data are from an article by L. W. Moxey, Jr., in Electrical World, Dec. 18, 1915.

TABLE XLI. LABOR COSTS FOR PULLING IN AND SPLICING CABLES

Size, B. & S. or Circ. Mil.	Pulling cable, cost per ft.	Splicing cables, cost per splice
Single-conduit:		
No. 14	$0.02	$1.10
12	0.025	1.20
10	0.03	1.38
8	0.035	1.40
6	0.04	1.55
5	0.045	1.70
4	0.05	1.85
3	0.055	2.00
2	0.06	2.20
1	0.0625	2.40
0	0.065	2.60
00	0.0675	2.80
000	0.07	3.05
0000	0.0725	3.30
250,000	0.075	3.55
300,000	0.0775	3.80
350,000	0.08	4.10

Size, B. & S. or Circ. Mil.	Pulling cable, cost per ft.	Splicing cables, cost per splice
Single-conduit:		
400,000	0.085	4.40
450,000	0.09	4.70
500,000	0.095	5.00
550,000	0.10	5.30
600,000	0.105	5.60
650,000	0.11	5.90
700,000	0.115	6.20
750,000	0.12	6.50
800,000	0.125	6.80
850,000	0.13	7.10
900,000	0.14	7.40
950,000	0.15	7.70
1,000,000	0.16	8.00
Duplex:		
No. 14	$0.03	$1.55
12	0.04	1.80
10	0.045	1.95
8	0.05	2.10
6	0.06	2.30
5	0.07	2.55
4	0.08	2.80
3	0.09	3.00
2	0.09	3.30
1	0.095	3.60
0	0.10	3.90
00	0.105	4.20
000	0.11	4.65
0000	0.115	5.00
250,000	0.12	5.40
300,000	0.125	5.80
350,000	0.13	6.20
400,000	0.135	6.60
450,000	0.14	7.10
500,000	0.15	8.00
Triplex:		
No. 14	$0.04	$2.20
12	0.045	2.40
10	0.05	2.60
8	0.055	2.80
6	0.065	3.10
5	0.075	3.40
4	0.09	3.70
3	0.10	4.00
2	0.11	4.40
1	0.12	4.80
0	0.13	5.20
00	0.14	5.60
000	0.15	6.10
0000	0.16	6.60

The figures given for pulling cable do not include rodding or fishing of ducts, which varies from $0.005 to $0.03 per duct foot.

Cost of Installing Street Lighting Cables in Boston. Electrical World, May 20, 1916, has the following: The Edison Electric Illuminating Company of Boston, Mass., has installed 2,644,518 ft. of No. 6, lead-covered underground cable in a recent five-year period at a total cost of $0.2524 per foot. The cable was insulated with 7/32-in. 30 per cent. Para rubber compound, covered with a 5/32-in. lead sheath without tin, and guaranteed at a working pressure of 10,000 volts.

The cost of installation was made up as follows:

	Total cost	Cost per ft.
Average cost of cable — 2,442,628 ft. purchased.		$0.1817
Installation cost, drawing in (by contract)....		0.0110
Miscellaneous construction costs:		
11,526 bonding connections at $0.63.........	$7,261	
12,794 cable splices at $2.60	33,264	
102,044 cable protectors at $0.49.............	50,001	
350 standpipe collars at $1.61	563	
250 cable splices at potheads, at $2.60..	650	
	$91,749	0.0347
Freight, teaming, stockroom expense. inspection at factory and after installation. testing, duct protectors, racking (with extra hangers), waste cable, installation under frost conditions		0.0250
Total cost per foot		$0.2524

Telephone Cable. Data, April, 1911, gives the following for average Chicago conditions during the 10 years previous.

TABLE XLII. ESTIMATED COST PER FOOT OF UNDERGROUND TELEPHONE CABLE IN PLACE

	100 Pr. 19 Ga.	150 Pr. 16 Ga.	200 Pr. 19 Ga.	300 Pr. 19 Ga.	400 Pr. 22 Ga.	600 Pr. 22 Ga.
Cost of cable only.	$0.4926	$0.9685	$0.7478	$1.0389	$0.7524	$1.1190
Miscellaneous material	.0046	.0118	.0115	.0138	.0142	.0156
Rodding	.0086	.0086	.0086	.0086	.0086	.0086
Pull in	.0130	.0150	.0150	.0150	.0150	.0150
Splicing labor	.0131	.0144	.0184	.0211	.0214	.0229
Total	$0.5319	$1.0183	$0.8013	$1.0974	$0.8116	$1.1811

Market price of copper 18 cents. Average distance between vaults, 300 feet.

No allowance made for freight, cartage, supervision or other overhead charges.

Cost of Underground Telephone Cable, Installed. The following diagram Fig. 27, reproduced from Data, May, 1911, is based on a copper price of 18 cts.

Cost of Jointing Underground Electric Cables. H. Almert is authority for the following data collected by a large central station in the Middle West.

Size	Material	Labor	Total
No. 6 — 1/c Straight	$0.70	$0.90	$1.60
No. 5 — 1/c Y	1.20	1.35	2.55
No. 2 — 1/c Straight	.90	1.05	1.95
No. 2 — 11c Y	1.30	1.50	2.80
1/0 — 1/c Straight	1.15	1.35	2.50
1/0 — 1/c Y	1.50	1.80	3.30
1/0 — 4/c Straight	4.15	2.75	6.90
2/0 — 3/c (20,000 V.)	5.30	5.30	10.60
4/0 — 3/c Straight	4.05	2.75	6.80
250 — 3/c Straight	4.25	2.75	7.00
4/0 or 250 — 3/c Y	14.20	8.00	22.20

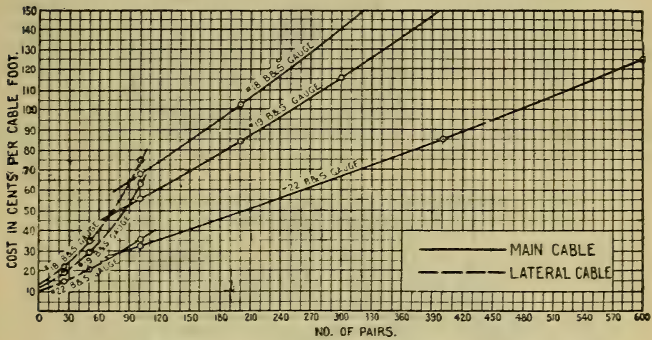


Fig. 27. Cost of underground telephone cable, installed.

Pulling Underground Cables in St. Louis. The following article was taken from Electrical World, August 22, 1914.

Supplying St. Louis with energy from the hydro-electric generating station at Keokuk necessitated tying the existing feeders of the Union Electric Light & Power Company to the 60,000-kw. substation which distributes the energy at St. Louis. The point at which the two systems are tied together is on the opposite side of the city from the main distributing substations, and the most modern methods were used to pull the underground cable through the conduits between these points.

The Union Electric Light & Power Company arranged the motors on its electric trucks so that they could be utilized in pulling the cables through the conduits. The adaptation of truck motors to this work, while not entirely new, is interesting in this case because of the ease with which the drive can be transposed from the truck wheels to the cable-pulling drum. The drum is supported above the motor on two rocker arms the common axis of which is not concentric with the axis of the drum. The drum is connected to the motor by a chain drive. When it is desired to convert the truck into a cable-pulling machine pins in the driving chains connecting the motor with the truck wheels are taken out and the chains taken off. The chain which is used to drive the cable drum

hangs on the drum sprocket, as shown in the diagram, Fig. 28, when the car is in motion, and by turning the eccentric which supports the drum the chain is made to engage with the motor pinion. Blocks are placed under the rear wheels of the truck to assist the brakes in preventing motion of the truck when the cable is being pulled.

After the drag line is threaded through the conduits in which the cable is to be placed, the men prepare the cable for pulling. This operation consists of slipping a special lubricating funnel over

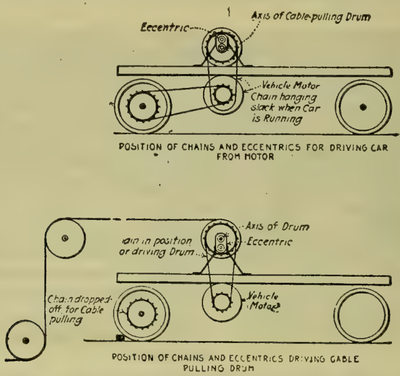


Fig. 28. Diagram of truck arrangement.

the end of the cable and fastening the drawing-in wire grip to the cable end. As the cable is being pulled through the conduits, oil is poured into the funnel. This lubrication serves to reduce the tension on the drawing-in wire and reduces the chances of the cable being bruised while it is being pulled through the conduit. The cables are all treated with a special fire-proofing material after they are installed and are tested for grounds to cable sheath for crosses and for continuity. From 4000 ft. to 7000 ft. of cable a day can be pulled in by this method, depending on the frequency of the manholes. This amount of cable represents a maximum of about fifteen reels a day. It is asserted that none of the cable which has been put in has been found faulty on account of the method of installing.

CHAPTER XIII

LIGHTING AND WIRING

Illumination in the past has been looked upon largely as an accessory. Modern illuminating engineering, according to C. E. Clewell on Industrial Illumination, June, 1912, is concerned with the adaptation of the available types of lamps to certain supply circuits, to various classes of service, and to given conditions of building construction.

A few years ago the older type of arc lamp and the carbon filament lamp, typifying a large and a small unit, covered the range of types of lamps available for illumination work in the

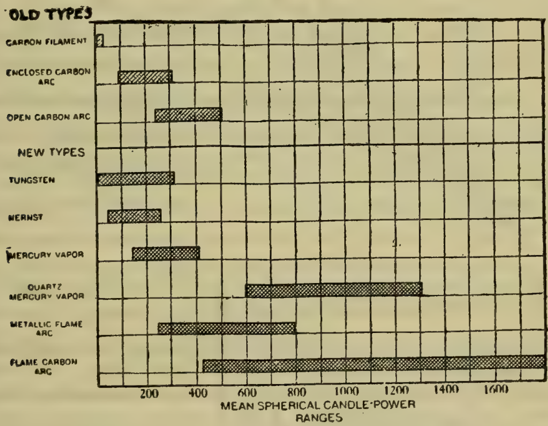


Fig. 1. Average candle-power ranges of old and new lamps.

industries. This limitation in candle-power has gone through an evolution by the introduction in more recent years of the enclosed arc, the open flame-carbon arc, the metallic flame arc and the long burning flame carbon arc lamp, as improvements on the original arc lamp; and the metallized filament, the tantalum and the tungsten lamps, as improvements on the original filament lamp. The Moore tube, the Nernst and the mercury vapor lamp are also available as new types.

The candle-power values of these various lamps are shown in Fig. 1 where, in an approximate manner, the average mean spherical

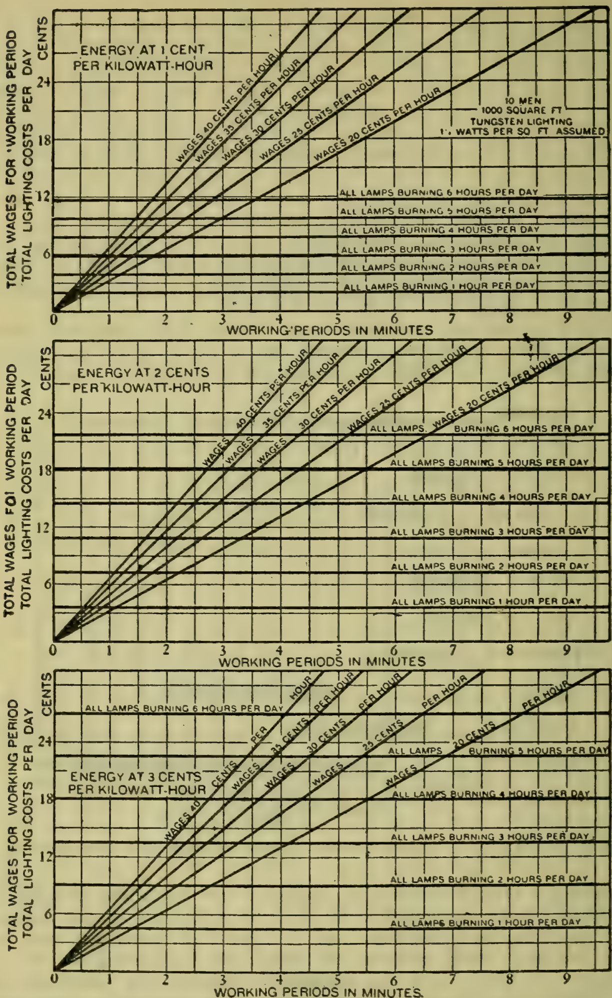


Fig. 2. Curves showing relation of average wages to lighting costs.

c.p. values of all types, both old and new are indicated. Fig. 2 shows the over-all dimensions of the various lamps from which it is apparent that the dimensions for given c.p. values have been modified by changes in design.

Re-directing the light where most useful should be included in development of high efficiency lamps as additional to the matter of total light flux per watt. The growing tendency to rate electric lamps according to the effective illumination produced on the work rather than in terms of the watts per mean spherical c.p. is evidence that this item will probably be included in the considerations of lamp efficiency more in the future than in the past.

Quantity of light is not the sole criterion of excellence; uniformity over the work, diffusion, adequate intensities on the sides of the work, absence of glare, color values and similar items are given an importance almost if not quite equal to vertically downward intensities.

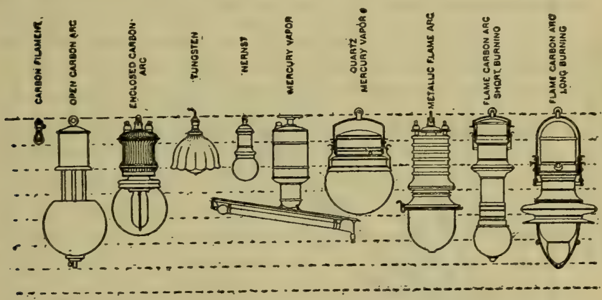


Fig. 3. Chart showing relative average overall dimensions of various lamps.

One Candle Power. The recognized unit of lighting measurement is a candle-power per hour. This is an arbitrary unit, originally the light emitted by a spermaceti candle burning 120 grains per hour, known as the British standard candle, but later modified to the "International Candle," which emits slightly less light than the British candle.

Factory Illumination Costs. Factory work generally speaking may be grouped into, (1) work on a horizontal plane, as bench work of some kinds which, in the main, requires only downward illumination; and (2) other work such as that included under machine tool operations, foundry moulds, rolling mills, assembly, and the like, where, in addition to vertically downward light, side components effective on vertical planes, as well as shadow elimination, play an important part in the excellence of results.

The height of ceiling, roof or trusses limits in a very large measure the size and type of lamp to be employed. Experiment and usage demonstrate the disadvantage of using very large lamps

for low ceilings, while lack of economy prohibits the use of small lamps for high areas. In former years arc lamps were used for low factory bays, while in some extremes no appreciable general illumination was possible, due to the absence of sufficient clearance between cranes and ceiling for an arc lamp. In like manner very high bays have been inadequately lighted, due to the lack of lamps possessing sufficient c.p. and suitable distribution characteristics. To-day, however, lamps of enormously greater c.p. and more suitable distribution are available for the higher area, while lamps with corresponding advantages are available for low areas.

Open spaces simplify the problem by permitting the use of lamps spaced comparatively far apart, while the interference of belting

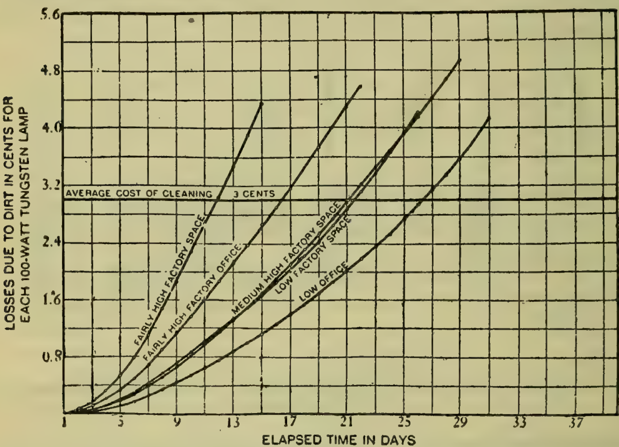


Fig. 4. Summary of curves of deterioration costs from Figs. 10, 11, 12, 13 and 14.

calls for a type and arrangement of lamps which will provide diffusion so as to reduce the shadows ordinarily produced by belts. In an atmosphere filled with dust and dirt a penetrating light should be employed, and in spaces of the latter class the maintenance is apt to be greatly increased with the rapid accumulation of dirt on the lamps and reflectors.

The arrangement of lamps should not be influenced primarily by the ceiling construction. Plans made up without regard to the ease of installation may sometimes be modified so as to yield equally satisfactory results, however, with a considerable reduction in first cost for installing, by taking into account certain features of the beams or girders.

The Spacing Distance of lamps is a first consideration. Ex-

periments have shown, for example, that in certain office locations with moderate ceiling heights, a spacing distance not exceeding 7 ft. 6 ins. is most advantageous. This results in a uniform illumination on the desks if the proper reflectors are used, and the light from a sufficient number of sources thus secured insures a diffusion of the resulting illumination. The directional features of the light are furthermore far superior to those cases where larger spacing distances are employed.

The spacing also governs the size of lamp to be used. As an illustration, whether one 250-watt or four 60-watt tungsten lamps are to be installed for a given area will be determined largely by the desired directional features of the light.

The Mounting Height should be determined on a basis of the avoidance of glare and of the ease in getting at the lamps for maintenance. The lamps should be mounted high enough to be out of the line of vision, and where the ceilings are too low to admit this, lamps of small size should be selected to reduce the quantity of light flux which enters the eye or is effective thereon when looking into any lamp.

Current Requirements for Lighting. A. L. Cook in Power, May 4, 1915, states that the usual votages employed for lighting are about 120 or 240 with a two-wire system and 120 for each side with a three-wire system. Either direct or alternating current may be used. Occasionally, three-phase or two-phase alternating current is employed for lighting, because of peculiarities in the conditions of supply. For alternating-current lighting 60 cycles is generally used, since 25 cycles is not as satisfactory owing to a flickering of the lights in some cases. It has been found, however, that tungsten lamps having a rating of 60 watts or more can be employed satisfactorily on 25 cycles. With ordinary inclosed arc lamps, 25 cycles is not satisfactory, although flame-carbon arc lamps can be used on this frequency. For direct-current motors, the standard voltages are 115, 230 or 550, and for alternating-current motors, 110, 220, 440 and 550 volts are commonly employed, although in some cases, for very large motors, 2,200 volts is used. The frequency may be either 60 or 25 cycles, and occasionally 40.

The voltages given for lighting and power service are the values at the lamps or motors. The standard generator voltages for direct current are 125, 250 and 600, and for alternating current, 120, 240, 480 and 600, which allows a reasonable drop between the generator and the load. In some cases a multivoltage system is used for motors, in order to give a ready means of varying the speed. This is not generally necessary, however, since modern direct-current motors permit wide speed variation by a change in the field strength.

The choice of a particular system for lighting or power service is affected by a number of factors, such as the character of the existing system or the central-station source of supply, and the relative sizes of the power and lighting loads. When an extension is to be made to an existing installation, the same system must

be used for the extension, unless the addition is so large or the requirements differ so widely that a change in the system or the addition of a different kind of supply can be seriously considered. For a new plant more freedom of choice exists, and the relative merits of the various systems will therefore be considered.

Direct vs. Alternating Current. For lighting, either alternating or direct current would, in general, be satisfactory, and the advantage of easy change of voltage in the case of the former makes it preferable in supplying buildings covering large areas. However, the lighting load is usually small, compared with the power load; hence the choice is fixed by the power requirements. The important advantages and disadvantages of alternating and direct current for power supply may be summarized as follows:

DIRECT CURRENT	ALTERNATING CURRENT
It is not generally feasible to use more than 240 volts for lighting. Therefore this limits the voltage of the system if supplied from the same generator as the motors.	The voltage can be easily transformed, using voltages suitable for lights and motors.
2. Maintenance is higher, owing to commutators.	2. There is no commutator; hence the motor is more rugged. It will stand larger momentary overloads, there is no danger of fire from sparks at the commutator and it is more reliable.
3. Wide speed variation of motor by simple means, with high efficiency.	3. Speed variation is difficult and the motor is less efficient at reduced speeds.
4. Motors have better starting characteristics for cranes and elevators.	4. Operation is not satisfactory on high-speed elevators and large cranes. Starting current is greater.
5. Starting current is lower for usual types of constant-speed motors.	5. Starting current for ordinary type is large. Special arrangements are necessary to reduce it.
	6. A somewhat larger generator is required for a given motor load.

The relative sizes of the power and lighting loads will have an important bearing upon the selection of the system. In some cases of light manufacturing, particularly if all the work is in one building, where the feeders would be short, direct current might well be used, employing 120 volts two-wire for small systems, and 240 volts three-wire, or possibly two-wire, for larger systems. If a two-wire system be used, the feeders would be about one-fourth as large for the 240 volts as for 120 volts; but, on the other hand, the lighting would have to be supplied at 240, which would entail somewhat greater cost for lamps and maintenance. It is better to operate the motors at 240 volts and supply the lights on a 120-240-volt three-wire system. By this means, the saving in size of feeders is nearly as great as if the entire load were supplied at 240 volts and the advantage of the lower-voltage

lamps is secured. The additional power-house equipment is of small cost.

For most industrial uses, the alternating-current motor is satisfactory, and in some cases almost necessary, either because of the great distances from the power house or the severe operating conditions due to dust, moisture, etc. Its principal disadvantage is the difficulty in adjusting the speed. With a direct-current system it is possible to obtain motors which will allow a speed change of three to one. When the speed is adjusted to a given value between these limits, it will remain practically constant regardless of the load. Such motors are extensively used for driving lathes and similar machine tools. It is possible to provide means by which the speed of an alternating-current motor can be adjusted to as wide a range as the direct-current motor, but usually at a sacrifice in efficiency; whereas, the direct-current motor has nearly the same efficiency at all speeds. Moreover, the variable-speed alternating-current motor, having been adjusted to a particular speed, will not maintain this as the load changes; instead, the speed will increase as the load decreases. This wide speed variation is objectionable where constant speed with varying load is necessary, as in machine-tool driving; but for some purposes, such as ventilating fans, centrifugal pumps, paper machines, and the like, where the load does not vary suddenly, the use of an alternating-current adjustable-speed motor is satisfactory. Alternating-current motors are not as satisfactory for cranes and elevators, owing principally to the difficulty of control, particularly when making stops. For this reason direct-current motors are to be preferred for high-speed elevators and large cranes. Therefore, in an office building where the elevator load is usually greater than the other motor load and the length of the feeders is not great, the direct-current system is preferable. For large buildings the three-wire, 240-volt system should be used, the motors operating at 240 volts and the lights at 120. Only in small buildings should the 120-volt 2-wire system be used.

If the building is not supplied from a power plant on the premises, but obtains its supply from a central station, the type of service will depend upon the system of the supply company. If only alternating current is available it will be best to use alternating-current elevators unless the speed is high (above 300 ft. per min.) rather than provide the necessary transforming apparatus. For industrial establishments in general, the alternating current is to be preferred unless the cranes and variable-speed tools form a large proportion of the total load. If it is absolutely necessary to use direct current for some of the motors, it is better to provide alternating-current service for general uses, with a direct-current supply for cranes and special work.

When installing any wiring it is desirable to conform in all respects to the local rules governing such installations. The rules of the National Board of Fire Underwriters, called the "National Electric Code," form the basis of most of the regulations which have been issued by various cities and other parties interested,

and must be followed in order to obtain fire insurance on property. These rules may be obtained gratis from the National Board of Fire Underwriters by applying to its New York, Boston or Chicago offices. The Inspection Department of the Associated Factory Mutual Fire Insurance Companies, with an office in Boston, has issued the "National Electric Code" with explanatory notes, thus giving in many cases more specific directions for the proper installation of electrical apparatus than is contained in the "Code." In many cases there are rules issued by the city inspection departments, which are substantially the same as the "National Electric Code," but care should be taken to see that the work not only meets the code requirements but also conforms to the local rules. In the following discussion the rules of the "National Electric Code" are followed.

Choice and Distribution of Lamps. The subject of the proper illumination of industrial establishments has in the past few years been given considerable attention on the part of factory superintendents and managers, who have begun to realize that it pays to provide sufficient illumination. Investigations have shown that an efficient lighting system increases the output from 2 to 10%, and it has also been found that the number of accidents is materially reduced when adequate lighting is provided.

For interior illumination of buildings, there are available the following types of lamps:

Lamp	Service
1. Carbon-filament	a.c. or d.c.
2. Gem- or metalized-filament	a.c. or d.c.
3. Tantalum	a.c. or d.c.
4. Tungsten, including "nitrogen" filled lamps	a.c. or d.c.
5. Inclosed-carbon arc	a.c. or d.c.
6. Metallic-flame or magnetite arc	d.c.
7. Flame-carbon arc	a.c. or d.c.
8. Nernst	a.c. or d.c.
9. Cooper-Hewitt mercury arc	a.c. or d.c.

While all of the foregoing types have been used for interior illumination, the practice has now become so standardized as to make the tungsten lamp by far the most common for ordinary heights of ceilings. The metallic-flame arc and flame-carbon arc are used for lighting large floor areas with high ceilings, particularly where there is more or less smoke and gas. The so-called nitrogen-filled lamp, which is a special form of tungsten lamp with the bulb filled with nitrogen or a similar gas, is very useful where large lighting units can be employed, and the tendency is to use this in place of the metallic-flame or flame-carbon arc, owing to the reduced cost of maintenance. The mercury arc has also been used extensively, principally because of its small power consumption, but it produces such an objectionable color that it is unsuitable for many uses and can better be replaced by the nitrogen-filled lamp. This gives a light even whiter than the ordinary tungsten lamp with a power consumption not much greater than that of the mercury arc. Present practice, therefore, for rooms

of ordinary height, has narrowed down to the use of tungsten lamps with glass or steel reflectors, mounted near the ceiling and arranged to give sufficient illumination to the entire room. In general, drop cords with individual lights have been eliminated as far as possible and are used only for special work which cannot be lighted from the overhead lamps. Where it is necessary to use individual lights, a 16-c.p. carbon-filament or a 40-watt gem lamp is used. The latter is preferable as it gives the same candlepower as the carbon and requires about 20% less power. The following gives data on the various sizes of tungsten lamps:

DATA ON TUNGSTEN LAMPS *

Size rated watts	Candle-power	Watts per candle-power	Life, hours	Approximate current, amperes 120 volts	240 volts
25	24	1.05	1000	0.21	0.11
40	39	1.03	1000	0.33	0.17
60	60	1.00	1000	0.50	0.25
100	105	0.95	1000	0.83	0.42
150	167	0.90	1000	1.25	0.62
250	278	0.90	1000	2.08	1.04
400	445	0.90	1000	3.33	1.67
500	555	0.90	1000	4.16	2.08
†200	222	0.90	1000	1.67	...
†300	353	0.85	1000	2.50	...
†400	534	0.75	1000	3.33	...
†500	714	0.70	1000	4.16	...
†750	1150	0.65	1000	6.25	...
†1000	1665	0.60	1000	8.33	...

*From figures supplied by the National Lamp Works of the General Electric Co. The above applies to 120-volt lamps; for 240-volt lamps the watts per c.p. are about 10% higher.
†Nitrogen-filled lamps of 120 volts only.

Power Required for Illumination with Tungsten Lamps. The power required to light a given floor area as given by A. L. Cook in Power, May 4, 1915, varies with the amount of light necessary, which in turn will vary with the character of the work carried on. Table I gives the number of watts required per sq. ft. of floor area for different classes of work, with various arrangements of tungsten lamps. These values are based on good practice and will give first-class illumination under average conditions. The principal item which would affect these values is the color of the ceilings and walls. For offices, stores, corridors and drafting rooms it is assumed that both the ceilings and the walls are fairly light in color, while for factories, warehouses and power houses they would be darker and less light would be reflected. The figures given for general office illumination are sufficient for usual office work, while those for special illumination should be used where bookkeeping or work of a similar nature is carried on. The amount of power allowed for a drafting room is sufficient to provide suitable illumination without the use of individual lamps. For rooms where rough manufacturing is carried on and where close application to the work is not required, the figures for general factory illumination should be sufficient; for fine machine

work, toolmaking and bench work, those for special factory illumination should be used. The lamps should be provided with suitable reflectors, in order to direct as much of the light as possible on the work. There is a great variety of these reflectors, but they can all be grouped in a few general classes, each of which is best adapted for particular conditions. There are on the market several types of glass reflectors which direct most of the light in a downward direction, but allow a certain amount to pass through to the

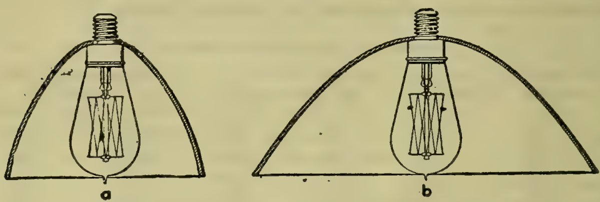


Fig. 5. Bowl type. Dome type.

ceiling. The best example of this type is the prismatic "Holophane." In order to have a good distribution of light, it is necessary to employ the proper style of reflector; hence a different size is manufactured for each size of tungsten lamp. It is necessary also to use the right type of shade holder in order that the lamp may be correctly located in the reflector.

Since modern systems of illumination are usually laid out to give practically uniform lighting over the entire floor area, it is necessary to use different types of reflectors for different heights of ceilings and spacings between lamps. The Holophane prismatic glass reflectors are made in three styles: "Extensive," for low ceilings; "intensive," for medium ceilings; and "focusing," for high ceilings. Glass reflectors are best adapted for offices, stores, drafting rooms and similar places, where it is desirable to light the walls and ceilings, as well as the work. They have also been used quite extensively for factory lighting, but are not suitable for use where there is danger of breakage.

Steel reflectors are made in a number of styles, with white porcelain-enamel surfaces, white painted surfaces, or aluminum painted surfaces. In general, the porcelain-enameled reflector is better than the others, owing to a great reflecting power, and the ease with which it can be kept clean. There are two general types of steel reflectors — the bowl, shown in Fig. 5-*a*, and the dome, in Fig. 5-*b*. These reflectors are made in various sizes to suit particular tungsten lamps, and in various shapes for different heights of ceiling. The dome type (*b*) should be used generally; the bowl type (*a*), which incloses the lamp more than the dome, being used only when the lamps are mounted so low that they would be in the line of sight of the workmen. When steel reflectors are used, the ceilings are not illuminated, except by a

small amount due to reflection from the benches or tables; but for many industrial applications this is not objectionable. In offices the steel reflectors do not give a pleasing effect. Values for either glass or steel reflectors are given in column A of Table I, since they are both classed as direct illuminants. For the same character of walls and ceilings there would be only a slight difference in the amount of illumination produced by the two types.

TABLE I. POWER REQUIRED FOR ILLUMINATION. TUNGSTEN LAMPS*

Class of work	Watts per square foot Direct A	Indirect B
Office — general	1.00	1.60
Office — special	1.25	2.00
Drafting room	2.00	3.20
Corridors and halls	0.50	0.80
Factories — general	0.80	...
Factories — special	1.50	...
Warehouses	0.50	...
Stores	1.25	2.00
Power house	0.80	...
Storage	0.30	...

*If nitrogen-filled lamps are used, multiply the watts per square foot as given above by 0.75.

HEIGHT AND APPROXIMATE SPACING OF LIGHTING UNITS. Sizes of lighting units for various mounting heights are as follows:

Height of Unit above Floor	Size of Unit, Watts
Up to 9 ft.	40 or 60
9 to 11 ft.	60 or 100
11 to 16 ft.	100 or 150
16 to 20 ft.	150 or 250
20 ft. and above	250, 400, 500 and nitrogen-filled lamps or flame arcs

Table II gives the approximate spacing distances for lighting units.

Comparison of the Cost of Lighting by Various Systems. R. Trautschold in the Scientific American Supplement, March 27, 1915, states that 5 gals. of kerosene oil is capable of giving out 4,500 c.p. if all waste is eliminated. With care the waste for 5 gals. of oil burned should not exceed 5 qts.

The cost of lighting a small cottage or flat for a year forms a very understandable comparison. Taking the average year in and year out, such an establishment — if the hall light is turned down low, the kitchen light extinguished when the last dish of the day has been washed and put away and all the other little economies that are insisted upon by the careful housekeeper — would burn an equivalent of about 100 c.p. 3 hrs. each day, or 110,000 c.p. during the year, illumination that would not be very excessive for one fairly large room.

In the days of the kerosene lamp, the 5-gal. oil can would have

TABLE II. APPROXIMATE SPACING DISTANCES FOR LIGHTING UNITS

Size of units, watts	Watts per sq. ft., direct *	Spacing distance	Size of units, watts	Watts per sq. ft., direct *	Spacing distance
40	0.3	11 ft. 6 in.	150	1.5	10 ft. 8 in.
40	0.5	9 ft.	150	2.0	8 ft. 8 in.
40	0.8	7 ft.			
			250	0.3	29 ft.
60	0.3	14 ft. 2 in.	250	0.5	22 ft. 5 in.
60	0.5	11 ft.	250	0.8	17 ft. 8 in.
60	0.8	8 ft. 8 in.	250	1.0	15 ft. 10 in.
60	1.0	7 ft. 9 in.	250	1.25	14 ft. 1 in.
60	1.25	7 ft.	250	1.5	12 ft. 11 in.
60	1.5	6 ft. 4 in.	250	2.0	11 ft. 2 in.
100	0.5	14 ft.	400	0.8	22 ft. 5 in.
100	0.8	11 ft. 2 in.	400	1.0	20 ft.
100	1.0	10 ft.	400	1.25	17 ft. 11 in.
100	1.25	9 ft.	400	1.50	16 ft. 4 in.
100	1.5	8 ft. 2 in.	400	2.0	14 ft. 1 in.
100	2.0	7 ft.			
			500	0.8	25 ft.
150	0.5	17 ft. 4 in.	500	1.0	22 ft. 5 in.
150	0.8	13 ft. 8 in.	500	1.25	20 ft.
150	1.0	12 ft. 3 in.	500	1.50	18 ft. 3 in.
150	1.25	11 ft.	500	2.0	15 ft. 10 in.

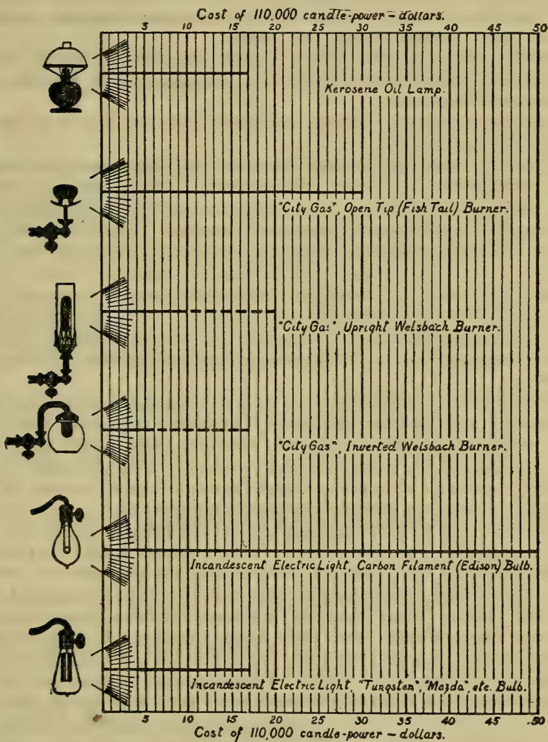
* The figures given apply to ordinary tungst lamps. In general the spacing of lamps should be about 50% greater than their height above the work illuminated.

to be replenished every 2 weeks or so, in such an establishment, for about 125 gals. of kerosene would be consumed during the year.

Ever since "city gas" first came into general use for lighting, the type of burner most commonly employed has been the ordinary open tip ("fish tail") burner, emitting a fan-like flame. Such a burner has a lighting capacity of about 20 c.p., and to obtain 110,000 c.p. about 27,000 cu. ft. of gas would have to be burned, or at least paid for, as there is bound to be a certain unavoidable leakage. This quantity would demand the use of unshaded lights only, for shades would, as in the case of oil lamps, lead to extra expense.

The upright Welsbach burner is very much more economical in the consumption of gas than the open tip burner for the same illumination, consuming only about one-third as much gas. The inverted Welsbach mantle is even more economical, due to the more efficient mixing of gas and air before it is ignited. This type of burner consumes but about one-fifth as much gas as does the open tip burner. For domestic purposes the incandescent electric bulb is almost universally used, and, until recent years, this meant the common carbon filament lamp — the Edison lamp. These lamps are made in various sizes, capable of emitting a definite amount of light — the usual *rated* candle-power being 16 and multiples of 16. The average consumption of electrical en-

ergy by such lamps, with clear glass bulbs, is very close to four and one-third watts for each *actual* candle-power, so that for 110,000 c.p. about 475 k.w. (1 kilowatt = 1,000 watts) would be required. As some shades or frosted bulbs would very probably be used in any private apartment or house, a more conservative figure would be 500 k.w.



Costs based on :— Kerosene at 12 cts. per gallon; "City Gas" at $1.00 per thousand cubic feet; and electricity at 10 cts. per kilowatt.

Fig. 6. Comparison of cost of lighting by various systems.

Bulbs in which the carbon filament is replaced by fine wires of a metal that becomes incandescent more easily than the carbon filament, known under various trade names, such as "Tungsten" and "Mazda," consume but about 1⅓ watts for each *actual* c.p., instead of nearly 4⅓ watts as do the carbon filament bulbs.

Cost of Operation of Practical Lighting Systems. Ward Harrison (Electrical World, November 15, 1913) states that in determining the total operating cost of any system of lighting, three items must be considered:

1. Fixed charges, which include interest on the investment, depreciation of permanent parts and other expenses which are independent of the number of hours of use. Frequently this item forms the greater part of the total operating expense, yet it is only too often omitted from cost tables.

2. Maintenance charges, which include renewal of parts, repairs, labor and all costs, except the cost of energy, which depends upon the hours of burning.

3. The cost of energy, which depends upon the hours of burning and the rate per k.w.-hr.

The life of a lighting system depends not only upon the wearing out of parts, but also upon obsolescence. There are no installations in this country which have been in use for a period of seven or eight years which are not already obsolete. Although the lamps may be in good operating condition, economy demands that they be replaced by more efficient illuminants. There is every indication that the next few years will see even greater progress in the development of lamps and the use of light. The rate of depreciation on all permanent parts is equal to at least 12.5%. The investment required in the tungsten system of lighting is relatively very low.

A table which would show the total operating expense of tungsten lamps for all sizes, with every discount from the list prices, for all possible periods of burning per year, and under all cost of energy, would be so large as to be entirely impracticable. From Table III, however, the operating expense of units under any set of conditions may be found with little calculation.

The total investment includes the cost of lamps, reflectors, holders and sockets. The investment in permanent parts is the total investment minus the price of lamps. No depreciation is charged against the lamps inasmuch as they are regularly renewed. The labor item under fixed charges provides for the cleaning of all units once each month. For the smaller units with steel reflectors the cost of cleaning is taken as $0.02 per unit for each cleaning. Data obtained from installations where accurate cost records are kept show that this figure is conservative for labor at $0.20 per hr. The cost of cleaning other reflectors is taken in proportion to the amount of labor required. Some illuminants require attendance at regular intervals. The cleaning is done at the same time and is, therefore, included under the maintenance charge. For units which require no regular attendance the cleaning expense becomes a separate charge. It will be noted that the fixed charges form only a small part of the total operating cost for a lighting system.

The maintenance charge is given for a 1,000-hour period of burning. To find the annual charge in any case it is necessary to multiply by the ratio of the total hours of burning to 1,000 hours.

TABLE III. TOTAL ANNUAL OPERATING COSTS — 100-VOLT TO 130-VOLT TUNGSTEN UNITS

	Energy cost, cents	Size of lamp, rated watts			
		40	100	250	500
	1	$1.16	$2.24	$4.93	$9.50
	2	1.56	3.24	7.43	14.50
1,000 hours' operation	3	1.96	4.24	9.93	19.50
per year.	4	2.36	5.24	12.43	24.50
Lamps bought on	5	2.76	6.24	14.93	29.50
$150 contract	6	3.16	7.24	17.43	34.50
	8	3.96	9.24	22.43	44.50
	10	4.76	11.24	27.43	54.50
	1	1.13	2.16	4.73	9.10
	2	1.53	3.16	7.23	14.10
1,000 hours' operation	3	1.93	4.16	9.73	19.10
per year.	4	2.33	5.16	12.23	24.10
Lamps bought on	5	2.73	6.16	14.73	29.10
$1,200 contract	6	3.13	7.16	17.23	34.10
	8	3.93	9.16	22.23	44.10
	10	4.73	11.16	27.23	54.10
	1	3.24	7.23	17.41	34.46
4,000 hours' operation	1½	4.04	9.23	22.41	44.46
per year.	2	4.84	11.23	27.41	54.46
Lamps bought on	3	6.44	15.23	37.41	74.46
$150 contract	4	8.04	19.23	47.41	94.46
	1	3.10	6.91	16.61	32.86
4,000 hours' operation	1½	3.90	8.91	21.61	42.86
per year.	2	4.70	10.91	26.61	52.86
Lamps bought on	3	6.30	14.91	36.61	72.86
$1,200 contract	4	7.90	18.91	46.61	92.86

TABLE IV. ANALYSIS OF OPERATING COSTS — 100-VOLT TO 130-VOLT TUNGSTEN UNITS

	Size of lamp, rated watts			
	40	100	250	500
Cost of lamp, list	$0.350	$0.800	$2.000	$4.000
Cost of lamp, standard-package discount	0.315	0.720	1.800	3.600
Cost of reflector, standard-package discount	1.155	1.566	1.653	2.617
Cost of unit, standard-package discount	1.470	2.286	3.453	6.217
Annual fixed charges:				
Interest on total investment, 6%	$0.088	$0.137	$0.207	$0.373
Depreciation on reflector, 12½%	0.144	0.196	0.207	0.327
Labor, monthly cleaning	0.240	0.240	0.360	0.480
Total	$0.472	$0.573	$0.774	$1.180
Maintenance cost per 1,000 hours:				
Lamp renewals at standard-package discount	$0.315	$0.720	$1.800	$3.600
Lamp renewals at $150-contract discount	0.291	0.664	1.660	3.320
Lamp renewals at $1,200-contract discount	0.256	0.584	1.460	2.920
Energy cost per 1,000 hours at 1 cent per kw.-hr.	$0.400	$1.000	$2.500	$5.000

Where lamps are sold at other than the prices given, the proper correction should be applied. The renewal of lamps is the only maintenance expense.

The energy cost is given for a 1,000-hr. period with energy at $0.01 per k.w.-hr.

An example will illustrate the use of Table IV. It is required to find the total operating expense per unit per year for lighting a mill with 250-watt tungsten-filament lamps. The lamps are burned a total of 4,000 hrs. and are purchased at the discount obtained on a $150 contract. The cost of energy is $0.20 per k.w.-hr.

From the table we obtain the following:

(1) Fixed charges	$0.77
(2) Maintenance, 4.000 × $1.800	7.20
(3) Energy, 4.000 × 2 × $2.50	20.00
Total	$27.97

In Table III are included annual operating costs which have been calculated for a number of cases frequently met in industrial plants.

Cost of Street Lighting in Chicago. Ray Palmer (Electrical World, Aug. 9, 1913) states that to light one mile of street, using 23 flame-arc lamps, with underground wires, costs about $9,000, while if the wires are placed overhead the cost is only about $4,000. These figures include substation and feeder distribution costs. On some of the older residence streets, where the trees are well-grown and act as an obstruction to the light from arc lamps, a system of underground cables and tungsten lamps mounted in opalescent globes on the old gas posts has been installed. This type of construction costs about $8,000 per mile of street lighted, using 75 of the tungsten lamps staggered on both sides of the street and about 150 ft. apart, measuring on one side of the street.

Flame-arc lamps on underground circuits cost in 1912 $39.91 a year to maintain. To this should be added an interest charge on investment of $19.16 and a depreciation charge of $13.67, making the total yearly cost, according to Mr. Palmer's figures, $72.74 per lamp. While the lamps on overhead circuits cost as much to maintain the interest and depreciation costs are lower, bringing the total yearly cost down to $54.57.

The underground-cable tungsten-lamp street lighting is the most expensive form of public street lighting used in Chicago except gasoline lighting. The cost per unit is only $13.36 for cash maintenance of this type of lamp, but the interest and depreciation bring the total amount to $24.27 per lamp per year. As there are 75 lamps to a street mile, this means $1,820 a year to light one mile of street with series tungsten lamps as against $1,673 for flame-arc lamps on underground circuits and $1,255 for flames arcs on overhead circuits. The corresponding figure for gasoline lighting is $2,343.75.

Mr. Palmer made an interesting comparison between street-lighting conditions in Philadelphia and Chicago. Philadelphia has a population of 1,549,000 (1910), an area of 129 square miles with

1,752 miles of streets and alleys. Chicago has a population of 2,185,000, an area of 194 square miles with 4,400 miles of streets and alleys. The annual cost of street lighting in Philadelphia is put at $2,472,000, or $1,412 per mile of streets and alleys. The corresponding figure for Chicago is $1,038,700, or $234 per mile of streets and alleys for public lighting. According to these figures, Chicago spends less than 20% (per year per mile of street and alley lighting) of the similar expenditure in Philadelphia.

Attention has been given recently to the lighting of street crossings under the elevated-railroad tracks, or subway crossings, as they are called. There are about 625 of these subways in Chicago. The railroad companies will be forced to install and maintain lamps in 275 of these subways, the city being required to light the remaining 350. After an investigation a standard of one 16-c.p. lamp for each 400 sq. ft. of inclosed subway area was decided upon as sufficient.

Chicago was operating on Dec. 31, 1912, 13,830 arc lamps and 862 series tungsten lamps. The city also rented 920 arc lamps and 63 tungsten lamps from the Commonwealth Edison Company. The average number of arc lamps owned and operated wholly by the city during the year was 12,735. The average cash cost of the operation and maintenance of these 12,735 lamps is given as $34.26 per lamp per year. This sum does not include interest, depreciation, lost taxes, rent of offices in the City Hall, rental of poles belonging to other companies, nor the cost of work done for the Department of Electricity by other branches of the city government. Adding these to the "cash cost," the total cost per lamp per year is placed at $60.32. Of this $13.52 is credited to depreciation and $7.65 to interest. The contract price of rented arc lamps is $75 a year.

Analyzing the $34.26 given as the cash cost for operation and maintenance, the largest item is $10.60 paid for electrical energy to the Sanitary District. The next largest item of cost is $9.39 for lamp trimming, while repairs to circuits, conduits and posts cost $6.59, and carbons $2.84. The total cost of maintaining the municipal electric street-lighting system of the city in 1912 was $432,335.

Depreciation is figured at the following rates applied to original cost: Buildings, 1.08%; steam equipment, 4.1%; electrical equipment, 4.7%; repair-shop equipment, 10%; lamps, 6.66%; circuits, 4%; conduits, 3%; posts, 3.5%. The general interest charge is figured at 4% on the value of the electric-light system less the amount payable to the Sanitary District.

The number of gas lamps in use for street lighting on Dec. 31, 1912, was 15,740 and the number of gasoline lamps 8,678. The total number of municipal street lamps of all kinds in service in Chicago on Dec. 31, 1912, was 40,259.

Cost of Street Lighting in New York City. In his annual report for 1914 William Williams, commissioner of the Department of Water Supply, Gas and Electricity of the city of New York, shows the saving effected in the lighting of streets, parks and public

buildings by the substitution of incandescent for arc lamps. At the beginning of 1914 there were 2,643 miles of street and 19 square miles of parks to be lighted. There were over 40,000 electric lamps and 45,000 gas lamps. In round numbers, the cost of lighting the streets and parks of Greater New York was $3,382,000 in 1913. The city has contracts for street and park lighting with the various companies. The term of the contract is limited by statute to one year. The rates for nitrogen-filled tungsten lamps in Manhattan during 1915 are $70 a year for the 300-watt lamps and $77 a year for the 400-watt lamps. The cost of arc lamps was reduced from $90 to $85. Rates equally favorable were obtained in the other boroughs. At the time of the report over 13,000 gas-filled incandescent lamps were burning on the streets of the city, including all its boroughs.

Cost of Installing and Operation of Gas Filled Street Lights at Titusville, Pa. Electrical World, November 23, 1916, states that very favorable impressions have been received from the installation of series gas-filled lamps for street lighting service at Titusville, Pa. The old system consisted of Wood double-carbon open-arc lamps and some series incandescent and gas-filled lamps supplied with energy from a Brush arc machine. The present system, which includes the equipment given in Table III, was adopted after a study of the results obtained with series and multiple units. In this investigation 9.6-amp. nitrogen-filled units were connected in series with some of the old open-arc lamps. With this arrangement, the incandescent lamps were subjected to very unfavorable conditions due to the arc lamps sticking and producing current surges. Despite this severe test, some of the gas-filled lamps operated for eight months without attention or renewal. Although very satisfactory results were also obtained with multiple gas-filled units, the series system was adopted because it did not require radical changes in the existing distribution system and for other reasons.

In the new system, which includes 150 400-cp. lamps and 28 600-cp. units, the larger lamps are placed at points where the traffic is dense and the shade deep, 112 units being supported on mast arms and the remainder on center suspensions. Formerly, cables were used to support each lamp, but this has gradually been replaced by No. 3 Oneida chain, until now all are so equipped. Some of the chain has been in service 7 years without showing break or deterioration.

The use of reels for raising lamps has also been discontinued. As a substitute, galvanized iron half cleats have been attached to each pole, with the points downward, so galvanized-iron rings linked to the lamp chains can be hooked thereto. The weight of the fixture is sufficient to secure the ring in place against any ordinary effort to unhook it. To minimize the unauthorized handling of the hoisting equipment, the cleats are placed as high on the pole as can be conveniently reached, and a window cord with a snap hook is used to lower the fixture. With this arrangement only about one-half of the amount of chain formerly used is re-

quired, resulting in a much safer support and a neater appearance. Since the new fixtures are somewhat lighter than the old ones, and do not have to be lowered usually more than five or six times annually, the strain on the supporting equipment is considerably decreased. To make the entire overhead equipment more substantial and sightly, and at the same time facilitate raising and lowering of the lamps, the old wooden and pipe mast-arm sets have been replaced by "Pierce" galvanized-iron arms 8 ft. in length.

All lamps burnt out are replaced at once if reported prior to 9 P. M. The reporting of lamp outrages has been greatly facilitated by instructing policemen and firemen and all city employees to give the exact location of burned-out lamps as soon as discovered. Citizens are requested to do the same. Data regarding the lamps are kept in card index files. From a study of past records kept on these cards, made after the system had been in operation 252 nights or 2,520 burning hours, it was found that 21% of the lamps originally installed were still in service, and showed no marked depreciation in efficiency, despite their having been guaranteed for only 1,350 burning hours. The majority of these lamps were 600-c.p. units, indicating that the larger units have the longest life. Ninety-one lamps exceeded the guaranteed life by a total of 64,890 hrs., or an average of 713 hrs. each. Eighty-seven lamps fell short of the guaranteed life by a total of 20,680 hrs., an average of 237 hrs. each. This analysis covers all short-hour lamps, defective or otherwise.

Since the new fixtures are somewhat shorter than the old arc-lamp fixtures, they hang closer to the pulley, thereby raising the source of light somewhat. The average elevation is 25 ft., although this figure has been exceeded or decreased at a few points. At this height the refractor shades project the light practically to the center of the blocks, which are slightly more than 400 ft. long. In the alleys the lamps are hung midway between the blocks. Owing to the double loop suspension afforded by the use of the absolute cutouts in connection with the fixtures, they always hang plumb. In addition to installing the regular street lamps an attempt was made to encourage the use of ornamental post fixtures in the business district by installing three single-lamp posts with diffusion globes in front of the city hall and one in front of the public library. The use of natural gas for illuminating the waterworks plant has been discontinued and electric service substituted. Another improvement made about the same time was the provision of a chemical rectifier for charging storage batteries on the fire alarm system. This apparatus, which has been in operation several months, eliminates the necessity of a motor-generator set, requires very little attention and has been furnishing excellent service. The saving in energy expense alone has been said to be $8 a month.

While the fixed expenses of the new system, such as salaries, maintenance and operation, average about the same with the old system, the wear on lamp suspensions has been considerably reduced and there is a perceptible reduction in the quantity of coal consumed during the operation of the lamps. With the old system,

two men at $2 a day each were required to trim the arc lamps. Including occasional extra help, the labor therefor amounted to about $1,500 a year. The supply of carbons, globes, repair parts, brush copper, and the constant overhauling and adjustment of the fixtures cost $1,500, as near as can be estimated. These items have been eliminated, however, with the new system, since the annual supply of lamps has been cared for by the contract which calls for

TABLE V. COST OF EQUIPMENT AT TITUSVILLE, PA.

Generators and exciters	$2,050.00
Two 900-r.p.m., 3-phase, 60-cycle, 2400-volt revolving field, belted type Westinghouse alternators; and two 1000-r.p.m., 125-volt, compound wound, multipolar belted-type exciters having 25% higher rating than required by the alternators.	
Constant current regulators and transformers	1,200.85
Three 30-35-kva., single-phase, 60-cycle, constant-current regulating transformers, with 2400-volt primaries and 6.6-amp., air-cooled secondaries.	
Switchboards and equipment	1,100.00
Complete station and substation switchboards equipped with all necessary instruments, switches, etc. (Westinghouse.)	
Street fixtures and cutouts	1,870.00
180 series incandescent street fixtures (Adams Bagnall Abolites) equipped with General Electric absolute cutouts, 20-in. concentric-ring reflectors, and 8.5 in. double-prismatic refractors. Fixtures and cutouts both wired with 18 ins. of No. 8 high-tension stranded wire, and furnished with four brass-wire connectors having brass screws.	
Lightning arresters and posts	447.28
Lightning arresters for station and substation complete, and four cast-iron ornamental single-lamp posts. (Westinghouse and Cutter posts.)	
Lamps	1,107.98
Two complete installations of 6.6-amp., 400 and 600-cp. nitrogen-filled lamps, and 200-watt multiple lamps for post fixtures. (Colonial.)	
Installation, including inspection, supplies, readjustment of these circuits to balance the phases, labor, building out for new lights and the removal of old system	1,214.27
Total	$8,990.38

their replacement. So far the records indicate that the replacement of lamps will not exceed $1,600 a year. The city electrician now attends to the entire system, excepting the station, additional help being employed only for heavy repairs and building lines for new lamps. These arrangements have permitted an annual saving of $1,400 a year aside from that represented by the improved fuel economy, the more efficient method of charging storage batteries, and lighting of the waterworks, which can be estimated at a total of $2,000 annually.

Between the award of the contract and the arrival of the new equipment a new brick and concrete substation was erected in the center of the city large enough to accommodate the street lighting switching and voltage control equipment, and also an office for the

city electrician. The building of the substation was more than paid for by the sale of old equipment removed from the street lighting system and sold for scrap. The generating equipment was installed in the city waterworks building, where a 175-hp. Russell steam engine was used to drive the generators.

Cost of Gas and Electric Lighting Compared. In a large American city where the price of gas is 80 cts. net and the price of electricity 10, 5 and 3 cts. net employees of the electric-service company have made up interesting tables to show the comparative costs of gas and electric lighting on the basis of equivalent illumination. These data, given in Electrical World, Aug. 8, 1914, are shown in Tables V and VI.

TABLE VI. COST OF GAS LIGHTING

(Gas at 80 cts. per 1000 cu. ft. Does not include mantles)

Hours' use	Single reflex	Four mantle inverted arc	Standard welsbach	Four mantle upright arc
1	$0.0059	$0.0178	$0.0073	$0.0234
2	.0089	.0298	.0117	.0410
3	.0119	.0418	.0161	.0586
4	.0149	.0538	.0205	.0762
5	.0179	.0658	.0249	.0938
6	.0209	.0778	.0293	.1114
7	.0239	.0898	.0337	.1290
8	.0269	.1018	.0381	.1466
9	.0299	.1138	.0425	.1642
10	.0329	.1258	.0469	.1818
11	.0359	.1378	.0513	.1994
12	.0389	.1498	.0557	.2170

TABLE VII. COST OF ELECTRIC LIGHT FOR EQUIVALENT ILLUMINATION GIVEN IN TABLE VI

(At rate of 10, 5 and 3 cts. per kw-hr. net, including lamp renewals)

Hours' use	One 40-watt	One 100-watt	One 150-watt	One 250-watt
1	$0.0040	$0.0100	$0.0150	$0.0250
2	.0060	.0150	.0225	.0375
3	.0072	.0180	.0270	.0450
4	.0084	.0210	.0315	.0525
5	.0096	.0240	.0360	.0600
6	.0108	.0270	.0405	.0657
7	.0120	.0300	.0450	.0750
8	.0132	.0330	.0495	.0825
9	.0144	.0360	.0540	.0900
10	.0156	.0390	.0585	.0975
11	.0168	.0420	.0630	.1050
12	.0180	.0450	.0675	.1125

Comparative Costs of Gas and Electricity for Illuminating Purposes. B. K. Cash before the Indiana Gas Association in 1915 states that among the vast number of conditions that have a bearing on artificial illumination are: The different classes and scales

of rates, the innumerable types and sizes of units using either gas or electricity, and above all the local and specific conditions under which artificial light is obtained and operated, as, the space to be lighted, height and color of the walls and ceilings, the nature and requirements of the business using the light, quality of light desired, and the taste and fancies of the consumer; these all have to be determined locally. The usual information needed on costs are only those of installation, maintenance and operation.

The rates here used are those in force in Indiana. The average electric rate for commercial and domestic lighting in all cities of over 10,000 population — including municipal owned plants — is 7.9 cts. per kw.-hr. The average maximum rate charged for artificial gas in 18 cities of over 10,000 population, or all those using straight artificial gas, is $0.97 per 1,000 ft. Taking these figures as a basis it would be fair to use $0.08 per k.w.-hr. as the average electric rate, and $1 per 1,000 cu. ft. as the average gas rate.

TABLE VIII. AVERAGE COST PER C.P. OF ELECTRICITY AND GAS

ELECTRIC RATE $0.08 PER K.W.-HR.

Lamp	Estimate candle power	Hourly consumption, watts	Cost per hour	Cost per candle power hour
46 Watt Tungsten.....	34	40	.0032	.000094
150 Watt Tungsten.....	134	150	.012	.000089
200 Watt Nitrogen.....	240	200	.016	.000066
740 Watt Nitrogen.....	1150	750	.06	.000052

Average cost per c. p. $0.000075.

GAS RATE $1 PER M. CU. FT.

Lamp	Estimate candle power	Hourly consumption, cu. ft.	Cost per hour	Cost per candle power hour
No. 3 Reflex...........	85	3.6	.0036	.000042
No. 10 Indoor Lamp....	228	9.0	.009	.000039
3 Mantle Invert. Arc...	439	15.0	.015	.000036
5 Mantle Invert. Arc...	632	25.0	.025	.000039

Average cost per c.p. $0.000039.

Table VIII has been compiled to show the average cost per candle power of electricity and gas. The figures shown are general, such as are used and accepted as applying to ordinary working conditions. Data are given on four of the most efficient lamps, from smaller units to the larger; their estimated c.p. and approximate hourly consumption, and from this the average cost per c.p. per hr. is determined.

Thus it is shown that it is possible at present day rates and with modern equipment to produce an equal amount of light with gas at about one-half the cost of electricity.

The field of out-door lighting is not entered on a large scale by

gas companies owing to the low electric rate made for this class of business. Quite an amount of outside store lighting is obtainable by means of the gas arc, and some companies are considering the advisability of installing such lamps in commercial districts on a revised flat rate basis as a profitable means of increasing their output. The plan is to figure the monthly consumption of the lamp, using the number of hours it would be lighted, and from this find the cost of gas consumed. To this add a reasonable amount for cleaning, lighting, extinguishing, repairing and depreciation, and overhead expense. Then from this total determine the net amount to be charged the consumer each month. The cost of installation is handled the same as any other construction account, mains, service or meter work, for the piping and lamps remain the property of the company and furnish service whenever required. An idea of the revenue to be gained along these lines is shown by the fact that a 3-mantle inverted out-door arc operated from dusk until 10 P. M. will consume in a year 22,380 cu. ft., and if burned until midnight, 33,330 cu. ft.

In residence lighting one of the strongest points in favor of gas is the increased amount of light obtainable for the money expended. Charges for installing gas and electricity in residences depend entirely on the grade of work desired and the scheduled prices in force. The average prices for piping and wiring are about equal. While a stated length of wiring can be run somewhat cheaper than same amount of pipe, the difference in this cost about equals the charge for accessories and extra runs for switches. In other words, the cost per outlet for either gas or electricity is practically the same. The fact that it is important to have all new buildings piped throughout for gas needs great emphasis. This really forms the keynote in securing additional home lighting. No matter whether the system used in a residence is gas or electricity, it is hard to induce the owner to undergo the tearing up required to change that system. So it is imperative that the established system be gas. While some lighting is secured by placing outlets in kitchens from fuel lines, and on first floors for portable lamps and bracket lights, yet to get the bulk of this business each room should be fitted with properly placed outlets to meet all requirements.

The cost of maintaining gas lighting in residences is a nominal one, and controlled largely by the installation. In a properly installed system of modern equipment, the cost of upkeep is greatly reduced over the old style burners. Breakage of mantles and glassware has been lessened in the newer lamps, which with the late reduction in the purchase price of mantles assists in minimizing the cost of maintenance. Where glassware is used with electric lamps the maintenance cost runs about the same as that of gas. The difference in favor of electricity in maintaining the lamps, about takes care of the repair charges on switches and the mechanical parts. To aid the lighting service, some companies have established a free house maintenance and inspection at stated intervals. They find it gives better satisfaction to both the com-

pany and consumer. Such a service can be made self-sustaining by the profit made in the sale of material; and at the same time helping to introduce modern equipment and stimulating the consumption of the lamps by keeping them in condition.

Electricity versus Gas for Street Lighting. T. Osborne in Electrical World, Dec. 14, 1912, gives the results of English tests by H. T. Harrison and J. A. Body as follows:

Two important streets were selected in the heart of the city, one lighted by electricity and the other by gas, and four lamps on each were subjected to close examination. The arc lamps are suspended along the center of the street, at a clear height of 27 ft. 6 ins. and at the following distances apart, 114 ft. 7 ins., 116 ft. and 132 ft. Tests were made from three sets of positions at a height of 15 ins. from the ground, (1) directly below each lamp, (2) at the center of the street half way between each lamp, (3) on the curbstones of the footpath half way between each of the lamps. These tests were for horizontal illumination. Direct-illumination, or candle-power, tests were made 4 ft. from the ground at the positions mentioned above and, in addition; at positions 6 ft. 6 ins. from a perpendicular from each lamp. The gas lamps were placed closer together, the distances ranging from 98 ft. 6 ins. to 118 ft. 6 ins. The lamps tested are of the "Metroplane" magazine flame-arc pattern, with clear inner globes and opalescent outer globes.

The electric lamps are connected eight in series on a 400-volt circuit, obtained from the ordinary distributing network supplied by the municipal plant. Each lamp takes an average of 583 watts, and the circuits are so arranged that every alternate lamp can be switched off when desired. The cost of the electric lamps is considerably less than that of gas lamps. The cost for electrical energy, depending as it does on the load factor, varies for the half-night lamps, which burn only 2,000 hrs. per annum, and the all-night lamps, which burn 4,000 hrs., being 2.14 cts. per k.w.-hr. for the former and 1.31 cts. per k.w.-hr. for the latter. Thus for one hour the cost for electrical energy would be (a) Half-night lamps, 583 watts, at 2.14 cts. per k.w.-hr., 1.248 cts.; (b) all-night lamps, 583 watts, at 0.655 ct. per kw.-hr., 0.764 ct.

To this must be added the cost of carbon electrodes and labor. Each lamp contains fourteen pairs of carbon electrodes, which during the tests exceeded five burning hours per pair. These electrodes as used at present cost $18.24 per 1,000 pairs; it follows that one hour costs 0.36 ct. It takes two men 15 mins. to trim and clean each lamp. A trimmer and an assistant are employed, earning respectively 14 cts. and 12 cts. per hr. Thus the trimming and cleaning, should the lamps be cleaned once in 50 hrs., would be 12 cts. per hr. Together with an allowance for repairs and for maintenance, this makes the total cost per hr. for the electric flame-arc lamp as shown in Table IX.

As lighting and extinguishing are automatically carried out by time switches, no charge has been allotted for this service. The relative capital cost of the plant and apparatus is as follows: The four arc lamps tested are a portion of sixteen along the same

TABLE IX. TOTAL COST PER HOUR FOR FLAME-ARC LAMP

	Half-night lamps, cts. per hr.	All night lamps, cts. per hr.
Electrical energy	1.250	0.764
Electrodes	0.360	0.360
Labor	0.120	0.120
Sundries	0.070	0.156
Total	1.800	1.400

street, which, including all accessories, are stated to have cost erected \$2,707, equal to \$170 per lamp.

The high-pressure gas lamps compare very unfavorably, as the total cost of the lamps, lanterns, poles, suspension and all accessories erected amounted to \$933, equal to \$233 per lamp. These figures do not include any amount for series street-lighting mains in the case of the arc lamps, or any for high-pressure gas mains or compressor plant. This obvious flaw is due to the peculiar system of accounts kept by the public authorities. The experts who tested the lamps commented on the absence of these items. The capital cost per mile of street would be as follows: For the arc lamps, 43.6 to the mile, \$7,532.08; for the high-pressure gas lamps, 49.34 to the mile, \$11,841.60. The relative constancy and reliability of the light sources were the next points to be considered. During the two months in which the four electric and four gas lamps were under inspection the maximum variations, exclusive of extinctions, were as follows: (a) Any one of the electric lamps, from 4,400 cp. to 2,420 cp.; all the arc lamps, from 4,400 cp. to 2,400 cp.; (b) any one of the gas lamps, from 2,058 cp. to 686 cp.; all the gas lamps, from 2,475 cp. to 686 cp. It is essential to point out that these variations frequently continued over only a short period and that they are not often noticeable, thus showing that the variation in illuminating power of the gas lamps is more than that of the electric lamps. The total number of complete extinctions noted by the experts during the two months' period was as follows: Arc lamps, June 14, one lamp out for 8 mins.; July 19, one lamp out for 20 mins. Gas lamps, June 16, one lamp out for 20 mins.; June 18, one lamp out for 60 mins.; June 23, one lamp out all night; July 21, one lamp out all night. The electric lamps thus worked in a more reliable manner. In comparing these results and failures it is essential to add that half the arc lamps burn all through the night; that is, twice the number of hours of the gas lamps. It follows, therefore, that the electric lamps are considerably more than twice as serviceable for street lighting, from this point of view, as the gas lamps. The difference in the degree of illumination throughout the streets, irrespective of the variations in the candle-power of the light source, was 4.5% for the arc lamps and 4.8% for the gas lamps. It will be noted, therefore, that there is little to choose between the gas lamps and the electric arc lamps in this respect.

It may be interesting to work out the reduction of costs to a

common basis of candle-power and illumination. The comparison on an equal basis of cost may be made as follows: From the details given it will be noted that for a cost of 1.4 cts. per hr. the arc lamps give an illuminating value averaging 2,970 cp.—that is, at the important angles, namely, 20 degs. to 25 degs. from the horizontal; while the gas lamps give under similar conditions only 1,750 cp., at the cost of 3 cts. per hr. Thus the candle-power at a cost of 3 cts. would work out as follows: Electricity at a cost of 3 cts. per hr. gives 6,364 cp.; gas at a cost of 3 cts. per hr. gives 1,750 cp., or electric lamps giving 2,970 cp. cost 1.4 cts. per hr. and gas lamps giving 2,970 cp. cost 5.08 cts. per hr.

From a comparison on an equal basis of illumination the arc lamps also have an advantage. Dealt with from this point of view the distances at which the lamps are spaced comes into the calculation, and as this varies owing to local conditions it will be desirable to take a unit length of street, say 1 mile, and to ascertain the number of lamps of either type which would be necessary to give the same illumination. As the arc lamps when spaced at an average distance of 121 ft., or 43.6 to the mile, produce a minimum illumination of 0.5 foot-candle when giving an average of 2,970 cp. at a cost of $1,220 per annum while burning for 2,000 hrs., it will be found by a simple calculation that 54 gas lamps giving an average of 1,750 cp. will be required to produce the same result, placing them in an inferior position as compared with the electric lamps. Further, as the gas lamps cost 3 cts. per hr.—equal to $60 per lamp per annum — when burning 2,000 hrs., the comparison works out as follows: Cost per mile minimum illumination, 0.5 foot-candle; for four arc lamps, $1,220; for four gas lamps, $3,240.

TABLE X. COMPARATIVE COST OF ARC LAMPS AND GAS LAMPS

	Arc lamps	Gas lamps
Candle-power of lamps	2970	1750
Number of lamps to the mile	43.6	49.34
Running costs per lamp per hour up to 11:30 p. m.	1.4 cents	3 cents
Capital cost per mile of streets	$7,531	$12,177
Running cost 1,000 cp.-hours	0.475 cents	1.714 cents
Cost per annum per mile equal illumination	$1,220	$3,240
Minimum illumination basis of comparison	0.5 ft.-candle	0.39 ft.-candle
Cost per mile of street per annum up to 11:30 p. m. at above illumination..	$1,220	$2,960

In the figures given above the cost of energy in the electric lamps is taken at the all-night rate. When they are taken at the half-night rate the cost would amount to $1,508. A general comparison of the two systems of lighting after 11:30 P. M. is interesting. The figures given above apply only up to the time when the gas lamps are turned out and every alternate arc lamp is shut off. When the gas lamps are put out the ordinary gas lamps of the old system, which is being gradually superseded, are

relied upon. After 11:30 P. M. the comparisons of cost for equal illumination are still more diverse, as in the case of the gas-lighted street in which the tests were made the low-pressure gas lamps, of which there would be eighty to the mile, and the cost of which cannot be taken at less than $9.60 per lamp per annum, give a minimum illumination of only 0.004 foot-candle for a cost of $768 per annum; whereas the alternate arc lamps give a minimum of 0.08 foot-candle, 20 times as much, at about the same cost.

Maintenance Costs of Arc Lamps for Street Lighting. L. L. Elden of the Boston Edison company before the Massachusetts Gas and Electric Light Commission in 1916 stated that for an average of 4,489 6.6-amp. magnetite arc lamps in service the yearly cost of trimming per l·mp was $9.94. The number of lower electrodes required was 277,726 and the average number of trims per year per lamp was 61.2. There were 3,828 hrs. of burning. The average service life per low electrode was 62.5 hrs., 70 hrs. being the maximum observed. No salvage is realized on the electrode stubs. The longest trim period, occurring in July, was about nine days. The route schedules for the various trimmers from week to week are made out by the head of the trimming department, who delivers the schedules to the stockroom at the headquarters of the work for the entire system of about 700 sq. miles. Requisitions for electrodes are signed by a representative of the installation or trimming department, who is in charge of the trimmers, after which the electrodes are taken from the stockroom to the loading platform, sorted and delivered by stock boys according to cabinets assigned to each trimmer. The stock boys apportion the electrodes according to routes, number of lamps per route and trimming period, and when the trimmers arrive at the plant before beginning a day's work no time is lost in waiting for electrodes.

An average yearly consumption of globes for the above number of lamps is 11,752, or 2.6 globes per lamp-year. Frequent changes are required by heavy slagging and pitting of globes, due to the mineralized material of the electrodes being thrown against the side of the globe. This is a cumulative process, and finally results in a bad appearance from the street. One standard size and shape of globes is used for magnetite lamps of the standard type throughout the system. Eighty-five per cent. of the globes are destroyed after being removed from the lamps, the remainder being cleaned of slag and soot and discoloration and used again. The yearly maintenance cost of the above lamps also includes an outlay of $445 for lamp parts, such as burned electrode holders, screws, globeholder rings, etc.

The transportation cost incurred in trimming lamps in Boston was $7,298. The total pro-rated labor cost in trimming in Boston proper was $11,108 for 15 trimmers and $2,250 for part time of clerks, stockmen and trouble men, or a total of $13,358. Eleven trimmers are engaged in regular service on regular routes; 1 trimmer does nothing but change upper electrodes, and 2 spare men are carried on the payroll. The copper electrodes are changed about once a year, the estimated life being 4,000 hrs. Trimmers

average 95 pole-type lamps per day each on regular routes. Twenty-four bracket-type lamps represents a day's work for a trimmer on account of their scattered location and the necessity for using an extension ladder in most cases.

A 6-day trim period exists during most of December and January. An automobile is of little use on trimming in congested districts compared with a horse and wagon. Trimmers report at 7 A. M. and report back at headquarters at 4 P. M, no circuit being operated until the afternoon report comes in. The total trimming labor was 4,490 days, for which the men were paid on an average $2.22 a day. Additional labor charges at a different rate were as follows: New trimmers were employed, requiring breaking in, aggregating 126 days at $2 each. There were also three men employed during the year to make a general overhaul of the magnetite lamps on the system, the charge for their time in Boston proper being $1,071. The grand total trimming charge for labor was $12,401. The number of upper electrodes changed was 3,893. During the year the company repaired 5,516 magnetite lamps. The average price paid for lower electrodes was 5 cts.

Experience with Thoran Arcs. Referring to the 1,600-cp. direct-current Thoran arc lamps of 500-watt rating used in the illumination of various public squares, Mr. Elden said that the cost of trimming, patrolling and labor per lamp is about $242 per year, the trimming costing $142. The income per lamp is only $148. The company did not anticipate a loss on these lamps when they were first placed in service. They were installed on account of the desire of the city to light large areas more economically than was feasible by the standard magnetite lamp. The performance was erratic, two trims a night being necessary at times. One such lamp usually replaced three or four magnetites. Owing to the high cost of operation the company has lately discouraged their extension, and at present but 24 are in service out of a maximum of about 40. The chief element of cost is the labor required to maintain continuous service. The lamps are widely scattered, and this increases the cost of patrolling and trimming. The lamps have to be changed frequently, brought into the shop for overhauling and repairs, and trimmed nightly. Mr. Elden estimated a fair price for these lamps under present conditions at about $325 per year each. This figure is based upon an investment average of $625 (the unit cost which the Boston Edison company figures for its entire street lighting system per arc lamp), with a fixed cost of $82.55.

Cost of Arc Lighting in Lynn, Mass. In Lynn, Mass., according to Electrical World, Sept. 6, 1913, the arc is carried 14.5 ft. above the sidewalk, the post being of the Lundin combination wooden and iron type as required by the Massachusetts laws, with fluted wooden column. There are in the complete installation 150 6.6-amp. ornamental luminous-arc lamps, two ornamental bracket lamps, one combination trolley and twin bracket pole with two lamps of the same type carried at a height of 27.5 ft., ten 4-amp. ornamental luminous-arc lamps of the parkway type carried at a height

of 18 ft., and one 4-amp. ornamental luminous-arc lamp of the residential type with the arc 12 ft. above the sidewalk. Of these, thirty-five 6.6-amp. lamps and all of the 4-amp. lamps burn all night. The cost to the city is $8,260 for the 6.6-amp. lamps burned until midnight and $2,884 for those burning all night, the parkway lamp service costing $906.40 a year, making a total cost for the entire service of $12,050.40 for the year. The standard pole is mounted on a concrete foundation 2 ft. square at the top, 3 ft. square at the bottom and 3 ft. deep, and each pole is provided with

TABLE XI. DATA ON LYNN (MASS.) ORNAMENTAL LUMINOUS-ARC LAMPS

	Number of lamps	Length of street	Average width of street	Average spacing in ft.	Total watts	Watts per sq. ft.	Watts per front ft.	Maximum Horizontal illumination, ft.-candles	Minimum horizontal illumination, ft.-candles	Average horizontal illumination, ft.-candles
Andrew Street	9	576	34	60.7	4,788	0.24	4.16	1.110	0.260	0.73
Munroe Street	14	828	32	60.1	7,448	0.28	4.50	1.000	0.275	0.68
Oxford Street.	11	665	36	55.1	5,852	0.24	4.40	0.990	0.290	0.62
Market Street before midnight	38	1686	60	45.2	20,216	0.20	5.60	0.751	0.113	0.42
Market Street after midnight	7	1686	60	278.7	3,724	0.037	1.10	0.459	0.0125	0.13
Market Street from City Hall Square to railroad viaduct ...	33	1260	57	38.9	17,556	0.24	6.97	0.751	0.115	0.47
Market Street from railroad viaduct to Broad St...	5	426	72	67.0	2,660	0.087	3.12	0.196	0.113	0.15

an absolute cut-out for lamp disconnection. At present there are 165 lamps in actual service, all being operated from mercury-arc rectifiers. The city of Lynn pays for the maintenance of the lamps, the prices being $70 per lamp a year for service until midnight and $82.40 for all-night service.

The cost of installation per pole was as follows:

Pole, including wiring and cut-out	$36.00
Twin cable wiring and absolute cut-out............	6.40
Casing to cover lamp mechanism	4.00
Excavation and forms for concrete	2.00
Concrete foundation	7.00
Replacing broken sidewalks of concrete	2.00
Painting	1.14

Teaming	0.50
Foundation bolts	0.40
Protective casings on pole	1.64
Total cost of pole	$61.08

In the previous installation the district was lighted by 45 4-amp. pendent-type luminous-arc lamps burning all night at a yearly cost of $82.40 per lamp, and these were removed in making the "white way" installation, the city being credited with $3.708, making the actual increased cost to the city for each year $8,342.40.

In general the lamps are staggered both on main and cross streets. The quantity and quality of light on the streets is at present probably unequaled, and notwithstanding the great amount of light coming from sources only 14.5 ft. from the ground, there is no glare and persons and objects can readily be distinguished

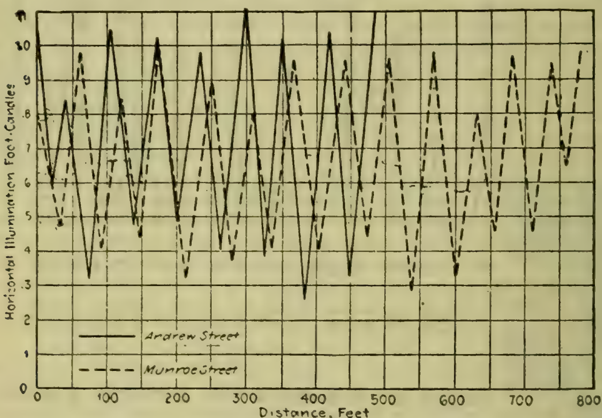


Fig. 7. Horizontal illumination curves for Andrew and Munroe Streets, Lynn.

from one end of the street to the other. On Market Street, the principal business thoroughfare of the city, 38 lamps are spaced an average of 38.9 ft. apart. After midnight there are 7 lamps burning the rest of the night. Illumination tests have been made on the principal streets with a Sharp-Millar photometer, readings being made opposite and half way between each lamp down the center line of the street. Readings made on Munroe and Andrew Streets, and the results are shown in Fig. 4.

Cost of Installing Luminous-Arc Ornamental System. A "white way" lighting system at Green Bay, Wis., described in Electrical World, Jan. 3, 1914, consists of 24 General Electric 4-amp. luminous-arc lamps extending over a distance of two 750-ft. city blocks. Posts placed opposite each other are installed on both curbs at

intervals of 60 ft. At the cross streets lamps are placed on each corner.

The 24 lamps are supplied with energy from a 75-lamp rectifier, connected into the same circuit with the 48 lamps of the local series magnetite street-lighting system. For the installation of this ornamental lighting system complete, ready to turn on, the cost was as follows:

1500 ft. No. 6 steel-taped cable	$333
Ornamental posts	492
High-tension cut-out switch for post	96
24 4-amp. luminous-arc lamps	840
Cementing posts and bolting to curb	158
Chiseling trench, laying cable in curb, and all necessary labor, including tunneling streets	540
	$2,459

For the 24 posts installed the cost complete has averaged approximately $103 per post. The items above entered were taken from the bills and are accurate. While the item of labor is a little high, this heavy construction cost is accounted for by the necessity of tunneling from curb to curb beneath an asphalt-paved street at two different points. In order to lay the cable it was also necessary to chisel between the concrete curb and the sidewalk throughout the entire 1,500-ft. distance. This cable is laid at a depth of 4 ins., and is covered with concrete. The method of installing the posts consisted simply in chiseling out, for a depth of 1 in., some of the concrete in the sidewalk to the size of the base of the post. The bolts were then anchored in place, and concrete was poured in the space, the posts being erected while the concrete was fresh. The resulting construction gives the post a solid foundation, besides making a workmanlike job in mounting the base flush with the sidewalk. The cable runs were made before the posts were installed, enough cable being left at each position to make the required connection to the cut-out switch in the base of the post. Access is gained to this switch by means of a hinged door placed in the base.

The operating charge runs $80 per month, based on a net rate of 5.9 cts. per kw.-hr. The lamps are burned daily from dusk to midnight, which is equivalent to 2,000 hrs. per year. As each lamp consumes about 300 watts, the company figures its own income at $40 per year per lamp, including maintenance, breakage, glassware, etc. Following are the figures for the cost of operating and maintaining the system, which agree closely with the preliminary estimates furnished by the manufacturers:

Energy for 300-watt lamp, 2000 hrs. per year, at 5.9 cts. per kw.-hr.	$35.40
Trimming and labor per lamp per annum	2.00
Electrodes per lamp per annum	1.40
Repairs per lamp per annum, covering 5 years' test	0.20
Rectifier tubes per lamp per annum	0.33
Average glassware renewals per lamp per annum	0.69
Total cost of energy consumed and maintained per lamp per annum	$40.02

As an alternative to the luminous-arc system an installation of tungsten ornamental lighting was first proposed for Green Bay, using five-lamp posts, each carrying five 100-watt lamps. At an operating cost of $6 per post the expense for 24 posts would have been $144 per month, or $1,728 per year. For a five-year period the cost would total $8,948. In such a tungsten lighting system, however, approximately 40 posts would have been required to take the place of the present 24-post luminous-arc system. With the latter posts, costing $3.34 per month to operate, the yearly expense is but $960, making the expense for five years $4,800.

Efficiency of Arc Lamps. C. E. Stevens (American Institute of Electrical Engineers, Aug., 1912) divides arc lamps into four types: (1) open carbon arcs; (2) enclosed carbon arcs; (3) metallic flame or luminous arcs; and (4) the enclosed flame-carbon arcs. The first two types have become practically obsolete as street illuminants. The metallic flame arc has largely replaced the older forms of lamps. The color of the light is white and the distribution shows a maximum candle-power from 15 to 25 degs. below the horizontal. The electrode life averages from 200 to 250 hrs., and the maintenance cost is comparatively low. The efficiency of light production varies from one-half to one watt per candle, depending upon electrode life and glassware equipment. The lamp is operated at from 4 to 7 amps., with an arc voltage of about 70. It operates only on direct current and is ordinarily used on series circuits from constant-current rectifiers.

The flame-carbon arc lamp has superimposed carbons, which give a life of from 100 to 125 hrs. The carbons are impregnated with a light-giving salt which furnishes a white or yellow light. The light distribution shows a maximum at from 20 to 30 degs. below the horizontal, similar to the metallic flame, which adapts it admirably for lighting streets or large areas. The volume of light is considerably in excess of the metallic flame lamp, and the efficiency of light production averages from 0.2 to 0.3 watts per candle. This lamp is the most efficient light source available for street illumination. It has been recently marketed in this country for operation on all commercial circuits, both alternating and direct current. For street illumination a series design is ordinarily used.

Maintenance of Arc Lamps in Street Lighting. In a paper read before the Armour Institute of Technology Branch of the A. I. E. E., A. B. Cornwell gave the following data on maintenance where a single arc lamp replaces two enclosed arcs for street lighting, costs being for one year:

	Two enclosed arcs	One flaming arc
Carbons	$2.86	$36.50
Trimming	2.34	8.21
Repairs	1.50	0.75
Inspection	0.90	0.90
Inner Globe	0.60	...
Outer Globe	0.30	0.15
Total	$8.50	$46.51

A flaming arc has to be trimmed once a day, while an enclosed arc needs to be trimmed but once a week.

Comparison of Arc and Incandescent Lighting in a Shop Building. Ward Harrison, of the General Electric Company, Cleveland, Ohio, submitted the following figures in a paper on the lighting of mill structures before the Association of Iron and Steel Electrical Engineers in 1913. In addition to the arc lamps, the original installation was supplemented by about 50 carbon drop-lamps over the individual machines. These were found unnecessary when the Mazda units were employed. It should also be noted, as pointed out by Mr. Harrison, that in addition to producing a much higher average intensity of light, the distribution from the tungsten units is far more uniform. The intensity from the arc installation, on the other hand, varied between 0.17 and 4.45 ft.-candles at points which required equally good lighting. In Table XII of data the carbon drop lamps are omitted.

TABLE XII. DATA ON LIGHTING OF A SHOP BUILDING

	220-volt arc lamps	110-volt tungsten lamps
Total number of lamps required	16	80
Height of lamps above floor, ft.	10	12.5
Height of test plane, ft.	3.5	3.5
Lamps per bay	1.25	4
Watts per lamp	750	150
Rated specific consumption, watts per candle	.....	1.12
Area of bay (12.5 ft. by 49.5 ft.), sq. ft.	618	618
Watts per sq. ft.	0.97	0.97
Average intensity, ft.-candles	1.15	5.25
Effective lumens, per watt	1.18	5.40
Annual operating cost per lamp (4000 hours)	$53.30	$13.85
Annual operating cost of installation	852.80	1108.00
Annual cost for equal illumination	3890.00	1108.00

Economics of Factory Lighting. M. H. Flexner and A. O. Dicker in Engineering Record, Oct. 18, 1913, state that it may be taken for granted that the volume of production in a well-lighted factory will exceed that of the same plant under poor conditions by from 8 to 15%, to say nothing of the benefit to the workman and the decreased liability to accident. The authors assume in a typical case that a 100-watt tungsten lamp is required for each man, and that it burns 3½ hrs. per day for 300 days per year under the conditions of electric service prevailing in Chicago, which enable the factory owner to purchase electricity for, say, an average yearly rate of 5 cts. per kw.-hr., with free lamp renewals. Taking the cost of the reflector at $1 and the cost of wiring per outlet at $4, the yearly fixed charges on this investment, with interest at 6% and depreciation at 12½%, amount to only $1. The cost of electricity for the year is then $5, and allowing 3 cts. per lamp per month for cleaning, the total yearly expense reaches $6.36, or 0.63% of a yearly wage of $1,000, which is a very small outlay in proportion to the factory labor cost. Looking at this question

from another angle, and assuming that adequate lighting in a specific case increases the output only 5%, the installation of 90 250-watt outlets, fixtures and reflectors at a cost of $517.50 in a factory of 30,000 sq. ft. of working floors will be paid for in much less than a year by the increased profit on the augmented output, taking the yearly business under the old regime at $83,333, secured under artificial light and allowing a 20% profit on the increased revenue of $4,166 resulting from the modern installation. In still another instance the cost of light per day, taking all charges

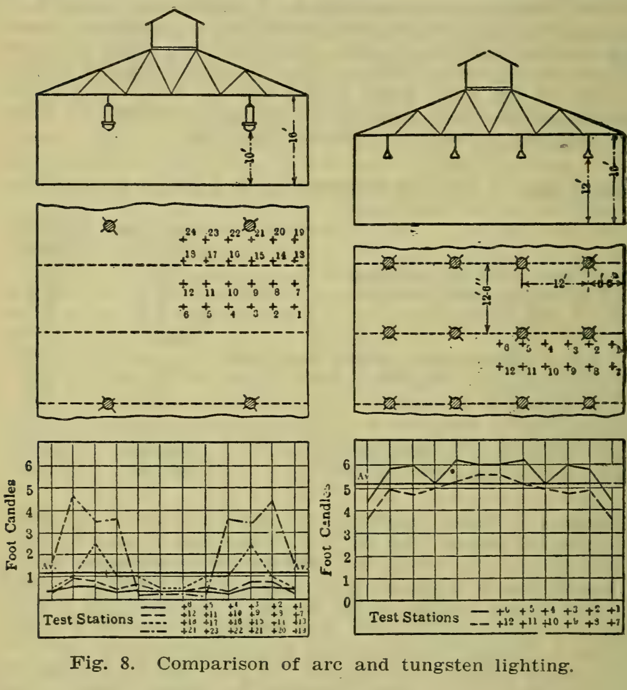


Fig. 8. Comparison of arc and tungsten lighting.

into account, came to barely 2 cts. per workman, the wage being $3.50. Under such conditions it is nothing less than absurd for a factory owner to spend, as was done in a particular case, $18,000 for a machine to be run by a high-priced operator of long experience, and then to refuse to spend $19 for lighting equipment in order that the work in process need not be taken to a window 20 ft. distant for calipering.

The Cooper Hewitt Light. This lamp differs from other commercial lights in that it produces its effect from a bar of luminous

vapor instead of from an incandescent solid. Because this method converts less of the energy into heat and more into visible radiations or light waves, it has decided elements of economy that are superior to the other types.

The light is blueish green in color, giving surrounding objects rather a strange and ghastly light at first. It is easy on the eyes and enables close work to be done with sometimes less fatigue than daylight.

The diffusion of the light is from a large tube instead of from a small point. It does not produce sharply defined shadows and makes less glare than most other illuminants and the cost of maintenance is supposed to be about half that of other commercial lamps.

For those to whom the blueish green color is objectionable the lights may be transformed by a parabolic rhodomain reflector which takes the place of the standard white glazed reflector and is based on the phenomenon of fluorescence. It transforms the light to an agreeable white color with a slight rosy tint.

The complete lamp outfit consists of tube, reflector-holder and auxiliary. The tube is made of clear glass with electrodes at each end and contains a small quantity of metallic mercury and causing the mercury vapor to glow.

The reflector holder supports the tube in two clamps and is attached to the auxiliary by pivot screws. The reflecting surface is finished in smooth white glazed enamel.

The auxiliary is enclosed in a sheet metal casing which is removable and which contains two inductance coils and an adjustor resistance by means of which the current must be regulated to the supply voltage. The auxiliaries for series lamps have a shunt resistance and a cut-out.

The direct current lamps cannot be used on alternating current without the intervening of rectifiers.

These lamps are made in a variety of sizes and styles, the price here net f. o. b., Hoboken, New York. For 100 to 124 volts at 3.5 amps., delivering 700 c.p. (mean hemispherical basis), with reflector; commercial efficiency, 0.55 watts per candle. (100–124 volts, one lamp is installed singly, on 200–248 volts two lamps are installed in series) on one lamp, tube reflector-holder and auxiliary for 100 to 124 volts cost $33. One lamp to be installed in series on 200 to 248 volts costs $34.

The approximate shipping weight of a single lamp outfit is 110 lbs., 6 lamps 400 lbs., and 12 lamps 650 lbs.

A tilting type is made and listed at $40 for the 124 volt double type. These lamps shipped weigh 725 lbs. The standard length over all is 51.75 ins., length of tube 43.75 ins. The tilting lamp has an over all dimension of 27.75 ins., length of tube 19.75 ins.

The quartz lamp for outdoor use has the following specifications: Voltage 100 to 125; average current 4 amp.; total watts 440; candle power 1,000; weight complete 27 lbs., packed for domestic shipment 110 lbs.

The 220 volts type carries an average amount of 3.3 amps.;

delivers 2,400 c.p. at a commercial efficiency of 0.31; weighs complete 33 lbs. net, and 115 lbs. packed for domestic shipment; prices $65 and $70 each respectively, covering complete outfit including burner, reflector-holder, auxiliary and globe.

Lighting of Railroad Stations with Gas. The following abstract of a paper by G. Hammel was taken from Progressive Age, Jan. 1, 1911. Gas is used quite extensively for lighting railroad terminals, stations and yards. One of the important points to be considered is the height of hanging the lamps on the poles in order to give the best light. Originally, before compressed gas was used, a height of 23 to 26 ft. had to be used for the gas light. At this height an area of 155 to 170 ft. was sufficiently lighted to read faint chalk marks on baggage. Four burners, each of 125 c.p., making a total of 500 c.p. light, were sufficient. This power is equal to electric lights of 700 to 800 c.p., and has, moreover, greater radiation and better penetration of air in case of a fog.

Since compressed air has been placed on the market, conditions are even more in favor of gas lights. The lights can be raised to poles 39 to 46 ft. high with 232 to 265 ft. distance between poles, giving greater horizontal light radiation and better illumination than electric lights. Usually 500 c.p. lights are placed at a height of 25 ft., with the distance between poles 160 to 180 ft., giving efficient light for any railroad station.

Connection of gas supply to lamps is best made by automatic connections, as they are easier to attend to and maintain, even though more expensive at first. Now we come to the principal points in this discussion — namely, the first installation costs, the operating costs and the question of service. We are speaking of lights on high poles only.

Electric Light. On 30 poles for a terminal, each lamp using 8 amperes, 600 c.p., at $175 per pole = $5,250.

Gas Light. For 30 poles with four burners, inverted gas mantles, using 13 cu. ft. of gas and 500 c.p. (equal to light of electric lights), each $200 = $6,000. In case poles of cheaper construction are used, each costing $150, the cost is only $4,500. This comparative statement shows that the initial expenses for both systems of light are about the same.

Operating Costs. Electric Light for railroad station with 30 pole lights and 200 electric lamps burning four hours a day.

30 poles for electric arc lights at 8 amps. and 600 c.p. using 500 watts an hr., 6 cts. per kw.-hr.	$0.03	
Carbons per hour	0.003	
	$0.033	
Daily burning four hours equal to 4 × $0.033 = $0.132, or per year equal to 30 × 365 × 0.132 =		$1.445.40
200 wire lamps using an hr. 50 watts at 50 c.p. each, 6 cts. per kw.-hr.	$0.003	
Lamp renewal per hour	0.002	
	$0.005	
Daily four hours equal to 4 × 0.005 = $0.02, or per year 200 × 365 × .02 =		$1,460.00
A total of		$2,905.40

Gas Light. The cost of gas is 0.112 cts. per cu. ft., or $1.12 per 1,000 cu. ft. of gas.

30 pole gas lights with normal pressure gas, four inverted burners, each using 3.6 cu. ft. gas, or a total of 14.4 cu. ft. gas, at 0.112 cents per cu. foot, equal to	$0.017	
Mantles and chimneys	0.001	
	$0.018	
Burning 4 hrs. a day	$0.072	
Per year 30 × 365 × 0.07		$766.50
200 inverted gas lights, inverted mantles, 80 c.p. using 2.4 cu. ft. gas	$0.003	
Mantles and chimneys	0.0004	
	$0.0034	
Daily 4 hrs. 4 × 0.0034	$0.0136	
Per year 200 × 365 × 0.0136		992.80
Total of		$1.759.30
Pole lights for 30 pole electric lights		$1,445.40
Pole lights for 30 pole gas lights		766.50
Gain of 45%		$678.90
Metallic electric lamps		$1,460.00
Gas light, mantles		992.80
Gain of 30%		$467.20

As regards tending to the lamps, the electric lights up to a short time ago had the advantage, as they could be turned on and off from the central station. But the long-distance lighters now used even up matters in this direction. The drawback to electric lights is that they are wired in series, and when the circuit is broken, all lights are extinguished, whereas in the case of the gas light, half of the lights can be extinguished, leaving the rest burning, giving sufficient light. Carbons of electric lights must be exchanged daily, while gas lamps need only be cleaned once every two or three weeks.

The Kaufman Lighting System. A system of lighting by means of lamps which vaporize kerosene oil was described in Iron Age, Jan. 23, 1913.

The method of operation is by pumping the oil into a steel tank made to withstand 10 times the pressure required. The air pressure forces the oil from the tank through a small bronze tube, which is very flexible and can be fastened on the ceiling or walls, run underground or strung on poles, and if necessary carried for long distances. A number of lamps located at various points can be supplied from one tank. The tank is provided with an automatic check and safety valve which in case of fire in the building releases the pressure and all the oil in the tubing is then drawn back into the tank. Should the tank be directly exposed to the fire the oil will burn out in a vertical flame, and it is claimed that explosion is absolutely impossible.

The air pressure from the tank forces the oil through the tubing into the vaporizer at the bottom of the lamp. A little time is

required, possibly two minutes, to start the lamp. This is done by pouring a small quantity of denaturized alcohol in the vaporizer and lighting it, so as to secure the necessary heat to gasify the kerosene. Considerable less time is required in this operation if a plumber's torch is used for heating the vaporizer. The gas thus formed is burned under a strong mantle, creating a light of intense purity and brilliancy.

The light does not flicker, but burns with a steady flame, and is unaffected by wind or a draft which would be liable to extinguish gas or ordinary vapor lamps. Its great brilliancy enables it to penetrate dust and fumes, such as are encountered in foundries, especially while pouring metal into molds. It is thus especially well adapted for general factory use. It has also been found very effective in outdoor lighting. Based on the current price of kerosene oil, a Kaufman lamp producing 1,200 c.p. is stated to cost about ½ ct. per hour, which is below the cost of maintenance of usual lighting systems.

The vaporizer used in this lamp is made of tungsten steel, nickel, silver and bronze, and while guaranteed for 10 years is almost indestructible. It can be removed from the lamp and cleaned in less than 2 mins. A gallon of kerosene will burn 14 hrs., giving 1,200 c.p. and 18 hrs. giving 1,000 c.p. The light can be regulated like city gas. It is made in a variety of styles for indoor and outdoor use. A contractor's lamp for outdoor use is an independent lighting plant in itself, having a stand made of tubing with a pressure tank at the foot and the light suspended from a hook at the top of the tubing. One form of lamp designed for portable purposes has a small annular tank above the reflector, the whole outfit in this form weighing about 22 lbs., and being easily detached from one location and carried to another as required.

Cost of Lamps. The following lamp costs are based discounts dated Sept., 1915, offered by the National Lamp Works of the General Electric Co.

Net value of contract	Discount standard package quantities. 10% without contract. Per cent.	Discount broken package quantities. Nothing without contract. Per cent.
Less than $150	10	0
$ 150	17	7
300	21	11
600	24	14
1,200	27	17
2,500	29	19
5,000	31	21
10,000	33	23
20,000	34	24
30,000	35	25
50,000	36	26
100,000	37	27
150,000	38	28
225,000	39	29
300,000	40	30

Note: Standard package discounts on all large style Mazda lamps can be given only on orders for exact standard package

quantities or multiples thereof. It is allowable, however, to combine in one standard package, all sizes of large style Mazda lamps having the same standard package quantity. Such lamps may be of different voltages and finish of bulb.

Mazda Class — Large style — Straight side — Ampere shape type, for 105 to 125 volts, Table XIII.

TABLE XIII. COST OF 105 TO 125 VOLT LIGHTS. (MAZDA)

Size of lamp in watts	Efficiency watts per candle	Standard package quantity	List price Clear	Frosty
		Straight Side		
10	1.25	100	$0.27	$0.30
15	1.10	100	0.27	0.30
20	1.07	100	0.27	0.30
25	1.05	100	0.27	0.30
40	1.03	100	0.27	0.30
60	1.00	100	0.36	0.40
100	0.95	24	0.65	0.72
		Pear-Shape		
100	1.00	24	1.00	1.05
200	0.90	24	2.00	2.02
300	0.82	24	3.00	3.10
400	0.82	12	4.00	4.15
500	0.78	12	4.50	4.65
750	0.74	8	6.00	6.25
1,000	0.70	8	7.00	7.25

TABLE XIV. COST OF 220 TO 250 VOLT LIGHTS (MAZDA).

Size of lamp in watts	Efficiency watts per candle	Standard package quantity	List price Clear	Frosty
		Straight Side		
25	1.20	100	$0.33	$0.36
40	1.12	100	0.33	0.36
60	1.10	100	0.45	0.49
100	1.00	24	0.80	0.87
150	1.00	24	1.20	1.30
250	0.95	12	2.00	2.15
		Pear-Shape		
200	1.00	24	2.20	2.27
300	0.92	24	3.60	3.70
400	0.90	12	4.80	4.95
500	0.85	12	5.40	5.55
750	0.82	8	7.20	7.45
1,000	0.78	8	8.40	8.65

Mazda Class — Large style — Straight side — Empere shape type, for 220 to 250 volts, Table XIV.

The efficiency watt per candle for the pear shape type is given in watts per spherical c.p. Pear shape lamps are not recommended "all frosted." If frosting is necessary, bowl frosting is preferred

and is particularly recommended for lamps of 300 watts or less which are to be used in interior lighting where the glare would otherwise be objectionable. Orders should specially state if lamps are to be burned in other than pendant positions.

Mazda Class — Large style — Straight side type for electric street railway service. The lamps listed are selected for amperes and are labeled for use, five in series, on 525, 550, 575, 600, 625 and 650 volts. They are rated in voltage groups, Table XV.

TABLE XV. COST OF ELECTRIC RAILWAY LIGHTS (MAZDA)

Number in series	Lamp voltage	Line voltage
5	105	525
5	110	550
5	115	575
5	120	600
5	125	625
5	130	650

Nominal watts	Efficiency watts per c.p.	Standard package quantity	List price Clear	List price Frosted
23	1.11	100	$0.27	$0.30
36	1.09	100	0.27	0.30
56	1.02	100	0.36	0.40
94	0.97	50	0.65	0.72

Gem or Carbon Class — Large style — Straight side and round types. Lamps of this type come in standard package quantities of from 200 to 250 with a straight side and in packages of 100 with a round type, Table XVI.

TABLE XVI. COST OF CARBON LIGHTS (GEM)

Size of lamp in watts	Efficiency watts per c.p.	List price Clear	List price Frosted
20	4	$0.20	$0.225
30	3	0.20	0.225
40	2.56	0.20	0.225
60	2.50	0.20	0.225
	Round Type		
50	2.50	0.25	0.280

Cost of Electric Conduit. The following costs are given by the General Electric Co., 1914:

ENAMELED CONDUIT

Size, ins.	Weight, lbs. per 100 ft.	Net price per 100 ft.
½	85	$54
¾	113½	72
1	168½	106
1¼	128	144
1½	273	172
2	369	231
2½	582	367
3	762	480
3½	920	580
4	1,089	685

Galvanized and sherardized conduits will cost above 5% more than enameled.

The above prices are net for amounts up to $50. An additional discount of 5% is given on orders of from $50 to $250 and above $250 a 10% discount is given.

Cost of Wiring. We have taken the following data from Electrical World, March 9, 1912:

Job 1. Sixteen outlets and twenty-two sockets. 22 × 50 watts = 1,100 watts total. 1,100 watts ÷ 16 (number of outlets) gives average of 69 watts per outlet. Under Class B the price for a job averaging 69 watts per outlet is $0.068 per watt. 1,100 × $0.068 = $62.70, socket wiring cost of job. (Switch wiring and switches to be added.)

Job 2. Seventeen outlets and twenty-two lamps. 1,100 watts ÷ 17 = 65 watts per outlet. Under Class B the price is $0.061 per watt. 1,100 × $0.061 = $67.10, socket-wiring cost of job.

TABLE XVII. BALTIMORE UNIT PRICE BASED ON WATTS WIRED

Average watts per outlet	Class of building A	B	C
50 to 55	$0.06	$0.07	$0.08
56 or more	Less 0.6 cent per watt for each watt over 55		
Over 75	0.04	....	....
Over 80	....	0.046	0.055
For convenience, use the following figures:			
50 to 56	0.060	0.070	0.008
57	0.059	0.069	0.079
58	0.058	0.068	0.078
59	0.057	0.067	0.077
60	0.056	0.066	0.076
61	0.055	0.065	0.075
62	0.054	0.064	0.074
63	0.053	0.063	0.073
64	0.052	0.062	0.072
65	0.051	0.061	0.071
66	0.050	0.060	0.070
67	0.049	0.059	0.069
68	0.048	0.058	0.068
69	0.047	0.057	0.067
70	0.046	0.056	0.066
71	0.045	0.055	0.065
72	0.044	0.054	0.064
73	0.043	0.053	0.063
74	0.042	0.052	0.062
75	0.041	0.051	0.061
76	0.041	0.051	0.061
77	0.040	0.050	0.060
78	0.040	0.048	0.058
79	0.040	0.047	0.057
80	0.040	0.046	0.056
81 and over	0.040	0.045	0.056

Wiring for Lamps, Outlets Only.— Obtain price as follows: Multiply number of lamps or sockets by 50 watts to get total watts wired for. Divide total watts by the number of outlets to obtain average

watts per outlet. On corresponding line in table find price (cents per watt) under class of building being estimated. Multiply the total watts wired for by this price per watt found in table. These prices are for wiring only — hardware extra.

TABLE XVIII. MULTIPLIERS FOR CONCEALED EXTRA WORK

For porcelain concealed work in Class A house multiply by....0.00
For porcelain concealed work in Class B house multiply by....1.05
For porcelain concealed work in Class C house multiply by....1.16
For flexible-conduit concealed work in Class A house multiply by.1.60
For flexible-conduit concealed work in Class B house multiply by.1.68
For flexible-conduit concealed work in Class C house multiply by.1.80
For wood molding, exposed work in Class A house multiply by..0.77

Table XVIII gives multipliers for concealed work for the different classes of buildings in Table XVII.

Wiring for Switches Only. For each kind of switch to be wired for, find price per switch outlet under class of building being estimated.

Per single pole	$2.00	$2.00	$2.50
Per set of two three-ways (one set used).....	6.00	6.00	7.00
Per set of two three-ways (two sets used at same outlets)	5.00	5.00	6.00
Per set of two three-ways with one four-way..	2.50	3.50	3.25
Two-point electrolier	2.50	3.50	3.25
Three-point electrolier	3.00	3.00	4.00

Job 3. Seventeen outlets and twenty-four lamps. 24 × 50 watts = 1,200 watts. 1,200 watts ÷ 17 = 70 watts per outlet. Under Class B the price is $0.065 per watt. 1,200 × $0.056 = $67.20.

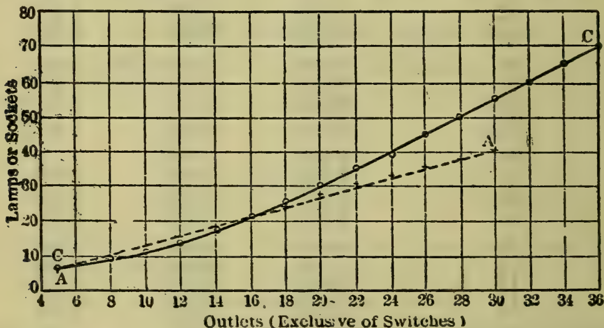


Fig. 11. Curves showing relation between numbers of outlets and rockets.

Note that the difference between Jobs 1 and 2 is one outlet, the addition of which adds $4.40, which is about right for the work done. Again the difference between Jobs 2 and 3 requires no additional work, two circuits being required in both cases, and the resulting price is only 10 cents higher for adding two lamps. Using

this scheme several men with only sales experience and no previous electrical knowledge were employed by the Baltimore company, and in less than a week were able to estimate wiring in completed residences and to close orders for it — which is the end desired.

Several points in the preceding schedule are, however, inconsistent. In some places, with certain combinations of outlets and lamps, the addition of an outlet does not increase the price to the customer, and in others the addition of a few lamps not requiring an additional circuit raises the cost. If the reader will not lose sight of the practical relation of outlets and lamps, as illustrated in Fig. 10, these circumstances will not be found serious, as they are negligible within the bounds of practical installations, and become harmful only where two or more customers compare the prices paid for work.

TABLE XIX. PRICE PER OUTLET WITH BASE CHARGE

Number of lamps	Price for total lamp outlets	Number of lamps	Price for total lamp outlets
1	$3.50	16	$47.85
2	6.90	17	50.50
3	10.20	18	53.10
4	13.80	19	55.65
5	16.90	20	58.15
6	19.90	21	61.60
7	21.90	22	64.00
8	24.90	23	66.35
9	27.90	24	68.65
10	30.90	25	71.90
11	33.85	26	74.15
12	36.75	27	76.40
13	39.60	28	78.65
14	42.40	29	80.90
15	45.15	30	83.15

To the above add base price for service entrances as follows:

	Overhead meter location		Underground meter location
	Basement	First floor	Basement
For 1 to 12 lamps (one circuit)	$4.00	$3.00	$2.25
For 13 to 24 lamps (two circuits)	4.75	3.75	3.00
For 25 to 36 lamps (three circuits)	6.00	5.00	4.25
For 37 to 48 lamps (four circuits)	7.25	6.00	5.25
For 49 to 60 lamps (five circuits)	8.75	7.00	6.50

For wiring to each switch outlet, add as follows:

One single-pole switch outlet controlling one-lamp outlet	$1.85
One set of two three-way switch outlets controlling one-lamp outlet	4.00
One set of two three-way switch outlets controlling two or three-lamp outlets	5.00
One set of two three-way and one four-way switch outlet controlling two or three-lamp outlets	6.50
One two-point electrolier switch controlling one-lamp outlet	2.25
One three-point electrolier switch controlling one-lamp outlet	3.00

Schedule of Contractors' Wiring Prices at Emporia, Kan. The schedule of wiring prices used by the representatives of the central

station in Emporia, Kan., described in Electrical World, Jan. 23, 1915, and the contractors is given in Table XX. Lamps are not included in the prices given.

TABLE XX. WIRING PRICES FOR FRAME HOUSES IN KANSAS

5 rooms with drop-cords	$13.00
5 rooms with drop-cords and porch lamp and switch	17.00
5 rooms with 3 drop-cords, two 2-lamp fixtures with shades, and porch lamp and switch	21.80
6 rooms with drop-cords	15.85
6 rooms with drop-cords, porch lamp and switch	19.85
6 rooms with 4 drop-cords and two 2-lamp fixtures and shades	20.65
6 rooms as above with porch lamp and switch	24.65
8 rooms (2-story) with drop-cords	20.55
8 rooms (2-story) with drop-cords and two 2-lamp fixtures and shades	25.35
8 rooms (2-story) as above with 3-way switch	32.35
8 rooms (2-story) as above with porch lamp and switch	36.35

Cost of Wiring Two-Story House. The following has been taken from the Electrical Age, July, 1917:

As an illustration of how the wiring of an average two-story house is figured, we give herewith, the wiring specifications and figures for such a house — the figures complete wiring for light and appliances. These data appeared in the pamphlet entitled "Wiring Your Share of Fifteen Million Homes." These specifications may be used as a model, for they represent standard practice in the wiring of already-built houses:

	Cost of wiring	Cost of fixtures
Cellar — One ceiling outlet and one snap switch	$4.74	No fixture necessary.
Laundry — One ceiling outlet	2.00	No fixture necessary.
Baseboard outlet for electric iron, electric washing machine, etc.	3.70	....
Porch — Ceiling outlet and single control push button switch	5.24	$2.90
Kitchen — Ceiling outlet	2.00	3.50
Dining room — Ceiling outlet and single control push button switch	5.24	....
Baseboard outlet for toaster, percolator, chafing-dish, fan, etc.	3.70	13.50
Living room — Ceiling outlet and single control push button switch	5.24	10.20
Upper hall — Ceiling outlet and single control push button switch	5.24	2.50
Bathroom — Ceiling outlet	2.00	2.50
Upstairs sitting room — Ceiling outlet and single control push button switch	5.24	10.50
Two bedrooms — Two ceiling outlets	4.00	13.70
Switch and mains	15.00	....
	$63.34	$59.30
Total cost of wiring and fixtures		$122.64

The Edison Electric Illuminating Company of Brooklyn, N. Y., gives the prices for 1914, Table XXI.

TABLE XXI. FLAT-RATE WIRING PRICES AND DEDUCTIONS IN BROOKLYN

KITCHEN	
No. 1 — Outlet consisting of a baseboard or wall flush receptacle, installed in kitchen on first floor, and one ceiling outlet with one-lamp fixture and pull-chain socket	$19.45
CELLAR	
No. 2 — Ceiling receptacle in cellar at heating apparatus with flush switch at head of cellar stairs	7.75
HALL	
No. 3 — Ceiling outlet in hall with one-lamp chain fixture and pull-chain socket (if wall bracket fixture is desired instead deduct 85 cents)	8.10
DINING-ROOM	
No. 4 — Dining-room outlet with three-lamp shower fixture, pull-chain sockets (if amber glass dome is desired instead add $1.50)	11.75
PIAZZA	
No. 5 — Outlet on piazza with ceiling fixture and globe with switch in hall	10.00
BEDROOM	
No. 6 — Bedroom outlet with two-lamp shower fixture, pull-chain sockets	8.00
PARLOR	
No. 7 — Parlor outlet with four-lamp shower fixture, pull-chain sockets	10.50
CHINA CLOSET	
No. 8 — China-closet outlet and bracket fixture with pull-chain socket	6.20
BACK PORCH	
No. 9 — Back-porch outlet and bracket fixture with switch	10.35
PANTRY	
No. 10 — Pantry outlet and one-lamp bracket fixture with pull-chain socket	6.20
BATHROOM	
No. 11 — Bathroom outlet and one-lamp nickel-plated fixture, pull-chain socket	6.20
ALL OTHER OUTLETS	
No. 12 — All other lighting outlets with one-lamp bracket fixture pull-chain socket	6.20
No. 13 — Two three-way switches for controlling hall lamp from upper or lower floor	9.90
No. 14 — Floor, baseboard, wall, or ceiling receptacles	4.95
No. 15 — Bell-ringing transformers for alternating current only	4.95
No. 15 — Bell-ringing transformers for alternating current only	4.95
No. 16 — Flush wall switches	3.85

INSTALLING RISERS

No. 17 — For each additional floor above first floor add...... 5.50

DEDUCTIONS FOR FIXTURES IF PERSONAL SELECTION IS DESIRED

No. 1	$1.30	No. 6	$3.05
No. 3	2.10	No. 7	5.50
No. 4	4.65	Nos. 8, 9, 10, 11, 12, each	1.25
No. 5	.70		

Boston Edison House-Wiring Campaign gives the schedule of wiring prices during 1913, shown in Table XXII.

TABLE XXII. SCHEDULE OF WIRING PRICES IN BOSTON

No. 1	Outlet consisting of a flush plug receptacle located in any room on the first floor anywhere excepting ceiling	$14.35
No. 2	No. 1 and outlet in cellar at heating apparatus with switch	19.00
No. 3	No. 1 and 1 outlet on piazza with switch in hall and fixture	22.00
No. 4	No. 1 and 1 outlet in hall with switch and fixture (three-way switches $6 additional)	23.00
No. 5	No. 1 and 1 outlet in parlor with switch and fixture	25.50
No. 6	No. 1; No. 2; No. 3	27.00
No. 7	No. 1; No. 2; No. 4	28.00
No. 8	No. 1; No. 2; No. 5	30.50
No. 9	No. 1; No. 3; No. 4	31.00
No. 10	No. 1; No. 3; No. 5	33.50
No. 11	No. 1; No. 4; No. 5	34.50
No. 12	No. 1; No. 2; No. 3; No. 4	36.00
No. 13	No. 1; No. 2; No. 3; No. 5	38.50
No. 14	No. 1; No. 2; No. 4; No. 5	39.50
No. 15	No. 1; No. 3; No. 4; No. 5	42.00
No. 16	No. 1; No. 2; No. 3; No. 4; No. 5	47.50
	Addition (to apply only after No. 3):	
No. 17	Dining-room outlet with switch and fixture	12.00
No. 18	Kitchen outlet with switch and fixture	8.25
No. 19	Pantry outlet and fixture	4.25
No. 20	China-closet outlet and fixture	4.25
No. 21	Back porch outlet with switch and fixture	8.00
No. 22	Second-story hall outlet with two three-way switches and fixture	11.25
No. 23	Bathroom outlet with switch and fixture	8.25
No. 24	All other lighting outlets with fixtures, each	4.25
No. 25	All other switches, each	4.00
No. 26	Floor or baseboard receptacles, each	4.00
No. 27	Bell-ringing transformer	4.00
	For each additional floor above the first floor:	
No. 28	Add $5 for Item No. 1 (extra charge is to provide for running risers through additional floors).	
No. 29	Add $10 for Items No. 1 and No. 2 (extra charge is to provide for controlling cellar lighting from the floor occupied by the user.)	
	Deduction if not wanted:	
	Switches (exclusive of cellar switch), each	3.00
	For fixtures if personal selection is desired:	
	Nos. 3 and 6, each	1.00
	Nos. 18, 19, 20, 21, 22, 23, 24, each	1.25
	Nos. 4 and 6, each	2.00
	Nos. 5 and 8, each	4.50

Nos. 9 and 12, each	$3.00
Nos. 10 and 13, each	5.50
Nos. 11 and 14, each	6.50
Nos. 15 and 16, each	7.50
No. 17	5.00

Cost of Wiring and Conduit Work for a Power Plant. The following power-plant cost figures from Electrical World, Mar. 27, 1915, were made up after many cases were tried out in various parts of the country. In using Table XXIII all expensive fixtures, apparatus, etc., are not included. The per cent. is based on the actual wiring materials, including switches, fuses and cutout boxes. The same figures apply to lead-incased wire, No. 6 and smaller.

TABLE XXIII. ELECTRICAL LABOR COSTS FOR STATION WIRING WITH RUBBER-COVERED COPPER WIRE

Size of wire	Cost of labor; per cent. of cost of material
No. 14	100
No. 12	100
No. 10	80
No. 8	60
No. 6	40
No. 4	30
No. 2	25
No. 1, 1/0, 2/0, 3/0	20
No. 4/0 and cables	18

Table XXIV gives the cost to install wire and cable in conduit. This price, one that would be used for such purpose as appraisal, includes: material, labor, a contractor's profit and overhead expense. It will cover feeders, and branches in the usual building work. This should not be used for short lines having numerous outlets.

TABLE XXIV. COST FOR PULLING WIRE IN CONDUIT

Description	Dollars per foot
500,000-C.M. cable in 3-inch conduit	1.820
Two 300,000-C.M. cables in 2.5-inch conduit	1.210
Two No. 2/0 wires in 2-inch conduit	0.820
Two No. 1/0 wires in 2-inch conduit	0.620
Two No. 1 wires in 1.5-inch conduit	0.510
Two No. 5 wires in 1-inch conduit	0.250
Two No. 6 wires in 1-inch conduit	0.210

The average cost of all conduit bends in general wiring practice shows that from 20 to 50-deg. bends cost very closely the same and that above 50 up to 90-deg. bends cost a larger amount. It has been found that the cost of bending is a function of the diameter and in the usual lengths independent of the length of conduit being bent. The following table gives the labor charges to be added to the cost of the conduit. These costs are for field bending and are quite high when the diameter exceeds about two inches. In figuring

conduit bending to be done on the job, list all bends to be made under two heads, 90 degs. and 22.5–45 degs. Neglect all bends of less than 22.5 degs. and use about twice the 90-deg. price for bends greater than 90 degs.

TABLE XXV. COST OF BENDING CONDUIT

Size of conduit in inches	Dollars per bend — 90-degree bends	Dollars per bend — Bends from 22.5 to 45 deg.
3	1.000	0.900
2.5	0.750	0.600
2	0.350	0.250
1.5	0.250	0.150
1.25	0.250	0.150
1	0.150	0.100
0.75	0.100	0.050
0.5	0.100	0.050

Where a conduit is to be bent in a large radius, involving long lengths of pipe and several fittings, the cost of bending, exclusive of cost of assembling parts, is about two cts. per lin. ft. of bend as a maximum and an average of 1.2 cts. per lin. ft. for 1.25-in. conduit or smaller.

It is sometimes desirable to run a conduit between buildings underground. If the conduit is given a good wrapping with tarred canvas this will more than double its life. The cost for wrapping, including material and labor but no pipe or conduit, averages as shown in Table XXVI.

TABLE XXVI. COST OF WRAPPED CONDUIT

Size of conduit in inches	Dollars per foot
0.5 to 1.0	0.015
1.25	0.019
1.5	0.022
2.0	0.027
2.5	0.032
3.0	0.040

Labor Costs in Interior Construction. Louis W. Moxey in Electrical World, Oct. 23, 1915, gives Tables XXVII to XLV of labor costs for installing various kinds of apparatus. The data given, however, cannot be considered general in their applications, for conditions vary widely in the electrical contracting field. Every contractor should make his own tables and curves, utilizing his records for the purpose. In all the tables it is assumed that the rates for labor are 55 cts. per hr. for foremen, 45 cts. per hr. for wiremen, and 25 cts. per hr. for helpers. All figures given include an allowance for what has been found to be necessary supervision by the foreman in the class of work under consideration.

If the items entering into architects' and engineers' specifications were always given in succession from point of supply to the outlets, the chances of the electrical contractor omitting items in his esti-

mate would be considerably reduced. Whether or not the architects or engineers write their specification in that form, the contractor should prepare his estimate so.

If an engine is to be installed in the plant, the contractor's first items should be for engines, foundations, painting, etc. Next should come the item for generators. If these be belted machines, the belts could be included under this item. Then should come the dynamo cables installed and connected to the lugs of the dynamos and switchboard. This should be followed by the item of switch-

Page 2 Estimate No. 10,176

Item	Labor and materials	Unit price		
Light mains, three-wire	200 ft. 2-in. conduit, loricated..	$0.20	$40.00	
	3 2-in. L's, loricated	0.30	0.90	
	3 2-in. couplins, loricated....	0.10	0.30	
	1 2-in. condulet (three-wire)	...	2.00	
	600 ft. No. 0 D. B., N. E. C. S..	0.15	91.50	
	Labor, conduit	0.25	50.00	
	Labor, wire	0.05	30.50	
	Supports, junction box, etc...	...	7.00	$222.20

Example 1. Applying the detailed method to mains.

Page 3 Estimate No. 10,576

Item	Labor and materials	Unit price		
Light branches	400 ft. ½-in. conduit, loricated..	$0.06	$24.00	
	200 ft. ¾-in. conduit, loricated..	0.07	14.00	
	600 ft. No. 12 duplex, N.E.C.S...	0.03	18.00	
	200 ft. No. 12 single, N.E.C.S...	0.15	3.00	
	Labor, ½-in. conduit	0.08	32.00	
	Labor, ¾-in. conduit	0.09	18.00	
	Labor, No. 12 duplex	0.01	6.00	
	Labor, No. 12 single...........	0.08	1.60	
	Supports, etc.	...	3.40	$120.00
Outlets....	20 light outlet boxes, T. & B...	0.20	4.00	
	Labor	0.30	6.00	
	20 studs on supports, T. & B.....	0.15	3.00	
	Labor	0.20	4.00	
	5 switch boxes	0.25	1.25	
	Labor	0.30	1.50	
	5 switches, D. P., Cutter.......	0.80	4.00	
	Labor	0.20	1.50	
	Bushings, etc..................	...	5.00	30.25

Example 2. Applying the detail method to branch circuits.

boards installed complete with instruments, circuit-breakers, etc. This would practically complete the plant unless a storage battery was to be installed. A miscellaneous item could be inserted either at this point or under the general expense item at the end of the estimate covering the tests and if necessary the water rheostat.

The estimate should then include the following items in the succession here given, the costs of both material and labor being entered:

Connection of power and light feeders to switchboard.
Flexible tubing, junction boxes, conduits, etc.
Power feeders, mains and sub-mains.
Power panels, boxes, doors, trim and fuses.

Power branches.

Power outlets, such as switches, starters and the like, erected and connected, wiring between switches, starters, etc., and motors.

Motors and foundations, delivered, erected and connected.

This would complete the power portion of the estimate, and the lighting portion should follow, the items being taken in the order given below:

Light feeders, mains and sub-mains.

Panel boards, panel boxes, doors, trim and fuses.

Branches.

Outlets.

Expenses, cartage, freight, car fare, railroad fare, loss of time, inspection fees, shanty, telephone, bond, insurance and miscellaneous.

The same method should be followed in making an estimate for telephone, telegraph, fire-alarm, watchman's-clock, time-clock, annunciation and similar systems.

An estimate for light branches according to this detail method would appear as shown in Example 2.

TABLE XXVIII. COST PER KILOWATT FOR ERECTING BELTED GENERATORS

Size in kw.	Normal condition	Easy	Difficult	Cost of painting
1 - 5	$1.00	$0.75	$1.50	$0.60
5 -12½	1.00	0.75	1.50	0.60
12½-25	1.00	0.75	1.50	0.50
25 -50	1.00	0.75	1.50	0.40
75	0.80	0.60	1.25	0.30
100	0.75	0.60	1.20	0.25
150	0.60	0.50	0.90	0.20
200	0.50	0.40	0.80	0.18
300	0.40	0.30	0.60	0.15
500	0.30	0.20	0.50	0.12

TABLE XXIX. COST PER KILOWATT OF FOUNDATIONS FOR BELTED GENERATORS *

Size in kw.	Normal condition	Easy	Difficult
1 - 5	$2.00	$1.50	$3.00 to $4.00
5 -12½	2.50	2.00	3.75 to 5.00
12½-25	2.00	1.50	3.00 to 4.00
25 -50	1.50	1.00	2.25 to 3.25
75	1.20	0.85	1.80 to 2.80
100	1.00	0.75	1.50 to 2.50
150	0.85	0.60	1.25 to 2.25
200	0.75	0.60	1.00 to 2.00
300	0.60	0.50	0.90 to 1.80
500	0.50	0.40	0.75 to 1.50

* The items under this heading include the cost of labor and materials, which is the usual method of estimating this class of work. The figures are based on the average cubical contents of foundations specified by generator makers. If the electrical contractor is to furnish the belt or belts, the labor for putting them in place should be included.

TABLE XXX. LABOR FOR ERECTING SWITCHBOARD PANELS

	Dynamo panel without sub-base	Dynamo panel with sub-base	Feeder panel without sub-base	Feeder panel with sub-base
Cost per panel.....	$10.00	$12.00	$12.00	$15.00

TABLE XXXI. LABOR PER LEAD FOR CONNECTING SWITCHBOARD AND DYNAMO LEADS *

Size, B. & S.	Paper and lead	Rubber and lead	Rubber or slow-burning insulation
14-8	$0.33	$0.30	$0.21
6	0.45	0.41	0.28
5	0.55	0.50	0.33
4	0.66	0.60	0.40
3	0.80	0.72	0.49
2	0.87	0.79	0.53
1	0.92	0.84	0.56
0	1.00	0.90	0.60
00	1.04	0.94	0.63
000	1.08	0.98	0.65
0000	1.14	1.03	0.69
Circ. mils			
250,000	1.18	1.08	0.72
300,000-350,000	1.34	1.22	0.78
400,000-450,000	1.43	1.30	0.84
500,000-550,000	1.60	1.44	0.90
600,000-650,000	2.10	1.90	1.00
700,000-750,000	2.50	2.25	1.25
800,000-850,000	2.95	2.65	1.50
900,000-950,000	3.30	3.00	1.75
1,000,000	3.75	3.40	2.00

* These figures are the labor costs for soldering cables into lugs at the switchboard and generators, also for soldering light and power cables into lugs of switches on the switchboard. They include the cost of arranging the cables in a neat and workmanlike manner at these locations.

What might be called the semi-detail method can generally be used for quick estimating with fairly accurate results. It consists of a combination of the labor and material costs. Take, for example, the item of mains in an estimate. If made in detail, it would be as shown in Example 1.

It will be noted that the total cost for running 200 ft. of main consisting of three No. 0 wires is $222.20, or $1.10 per foot. The contractor could prepare tables of unit prices for all items in an estimate, such as for two-wire to nine-wire service connections, two-wire to five-wire mains, two-wire and three-wire branches, etc., showing their cost for buildings of various types of construction. The disadvantage of this method, however, is that a change in price of materials diminishes the accuracy of the tables.

TABLE XXXII. LABOR COSTS (IN CENTS) PER FOOT OF CONDUIT WORK *

	Steel-terra-cotta construction				Concrete construction				Slow-burning construction			
	Exposed		Concealed		Exposed		Concealed		Exposed		Concealed	
Size of conduit	Small am't.	Large am't.	Small am't.	Large am't.	Small am't.	Large am't.	Small am't.	Large am't.	Small am't.	Large am't.	Small am't.	Large am't.
½	7	6	6	4	8	7	7	5	6	5	6	4
¾	8	7	7	5	9	8	8	6	7	6	7	5
1	9	8	8	6	10	9	9	7	8	7	8	6
1¼	10	9	9	7	11	10	10	8	9	8	9	7
1½	11	10	10	8	12	11	11	9	10	9	10	8
2	12	11	11	9	15	12	12	10	12	10	11	9
2½	15	12	12	10	20	15	15	12	15	12	12	10
3	20	15	15	12	25	20	20	15	20	15	15	12
3½	25	20	20	15	30	25	25	20	25	20	20	15
4	30	25	30	20	40	30	30	25	30	25	30	20

* The figures given in the table of costs for conduit work are for work in new buildings and include the labor cost of preparing for and running rigid conduit per foot, as well as the labor on junction boxes. If conduits are to be installed in old buildings, the cost figures would be considerably greater than those given in the table, the percentage of increase depending on the conditions. However, for concealed work in existing buildings flexible conduit (see Table XVII) is generally used in order to do as little tearing out as possible.

TABLE XXXIII. FLEXIBLE-CONDUIT LABOR COSTS PER FOOT FOR CONCEALED WORK IN EXISTING BUILDINGS*

Size, inches	Slow-burning construction	Fireproof construction
½	$0.08	$0.10
¾	0.09	0.11
1	0.10	0.12
1¼	0.12	0.15
1½	0.15	0.20
2	0.20	0.30
2½	0.30	0.40
3	0.40	0.50

* The figures include cost of preparing for and running. There is little difference in cost whether the amount is large or small.

TABLE XXXIV. COST PER FOOT OF FISHING CONDUITS AND PULLING WIRES *

Size, B. & S.	One wire per conduit	Two or more wires per conduit
14	$0.005	$0.004
12	0.006	0.004
10	0.0065	0.005
8	0.0075	0.006
6	0.0085	0.0065
5	0.01	0.007
4	0.013	0.0075
3	0.016	0.008

Size	One wire per conduit	Two or more wires per conduit
2	0.023	0.013
1	0.025	0.016
0	0.03	0.02
00	0.04	0.023
000	0.045	0.025
0000	0.05	0.03
Circ. mil.		
250,000	0.055	0.04
300,000–350,000	0.065	0.045
400,000–450,000	0.075	0.055
500,000–550,000	0.08	0.065
600,000–650,000	0.09	0.075
700,000–750,000	0.09	0.085
800,000–850,000	0.10	0.09
900,000–950,000	0.11	0.09
1,000,000	0.12	0.10
1,250,000	0.12	0.10
1,500,000	0.12	0.10
1,750,000	0.12	0.10
2,000,000	0.12	0.10

* These figures are for large amounts of rigid or flexible conduit in either new or existing buildings. For small amounts the figures should be increased from 10 to 30%.

TABLE XL. LABOR COST OF INSTALLING PANELBOARDS AND BOXES

Number of circuits	Boxes — New buildings — Exposed	Concealed	Old buildings — Exposed	Concealed	Panels installed and connected	Doors and trim
1– 6	$1.00	$1.00	$1.00	$2.00	$1.00	$0.40
8–10	1.25	1.25	1.25	2.25	1.50	0.50
10–14	1.50	1.50	1.50	2.50	2.00	0.60
16–20	2.00	2.00	2.00	3.00	3.00	0.75
24–30	2.50	2.50	2.50	4.00	4.00	1.00

TABLE XLI. LABOR COST OF INSTALLING AND CONNECTING MOTORS *

H.p. of motor	Mounting — Floor	Ceiling	Wall
1 – 2	$1.00	$1.50	$1.50
2 – 5	3.00	4.50	3.50
7½–10	6.00	9.00	7.50
15	10.00	15.00	12.00
20	15.00	22.00	18.00
25	20.00	30.00	24.00
35	25.00	37.00	30.00
50	35.00	51.00	42.00
75	50.00	75.00	60.00
100	75.00	110.00	90.00
150	100.00	150.00	120.00
200	150.00	225.00	180.00

* Includes labor on supports.

TABLE XLII. COST OF LABOR FOR INSTALLING AND CONNECTING SWITCHES AND RECEPTACLES

Single-pole switches......	$0.20	Door switches...........	$0.20
Double-pole switches.....	0.25	Wall receptacles.........	0.20
Three-way switches......	0.30	Floor receptacles........	0.30
Four-way switches.......	0.25		

QUICK ESTIMATING

It is impossible to give an accurate method for quick estimating, as the accuracy of the results obtained is entirely dependent upon the experience of the estimator and his knowledge of the building to be wired. Some contractors base quick estimates upon the cubical contents of buildings, while others estimate the material required and assume the labor item to be a certain percentage of this. The writer has found that the only quick method that is satisfactory is one basing the estimate on the number of outlets and utilizing data obtained from previous installations of a similar nature.

Take the following example, which is the cost for wiring a new residence of brick and joist construction by the concealed-conduit method. The service cables were run down the outside wall, the meter being installed in the basement. The system was three-wire,

TABLE XLIII. LABOR COST OF INSTALLING OUTLET BOXES AND SUPPORTS

Type of outlet	Old buildings: Steel and terra-cotta	Old buildings: Slow-burning	New buildings: Concrete	New buildings: Steel and terra-cotta	New buildings: Slow-burning
Light outlets.....	$0.35	$0.30	$0.30	$0.25	$0.20
Fixture supports..	0.10	0.10	0.10	0.10	0.10
Switch boxes.....	0.35	0.30	0.30	0.25	0.20
Wall-receptacle boxes.........	0.35	0.30	0.30	0.25	0.20
Floor-receptacle boxes	0.50	0.45	0.60	0.40	0.30

TABLE XLIV. LABOR COSTS FOR INSTALLING MOTOR-CONTROL APPARATUS

Hp. of Motor	Switch and rheostat	Controlling panel complete, switch, rheostat, etc.
1 – 2	$0.75	$2.00
3 – 5	1.00	3.00
7½–10	2.00	4.00
15	2.50	5.00
20	3.00	6.00
25	3.50	7.00
35	4.50	9.00
50	6.00	11.00
75	8.00	13.00
100	10.00	15.00
150	12.00	17.00
200	15.00	20.00

TABLE XLV. LABOR PER FOOT OF WIRE FOR INSTALLING CONCEALED KNOB-AND-TUBE WORK

Size of wire, B. & S.	New buildings	Old buildings
14	$0.01	$0.03
12	0.01	0.03
10	0.01	0.03
8	0.012	0.035
6	0.015	0.045
5	0.018	0.055
4	0.02	0.06
3	0.023	0.07
2	0.025	0.075
1	0.03	0.09
0	0.03	0.09
00	0.035	0.11
000	0.035	0.11
0000	0.04	0.12

110-220-volt, single-phase. The panelboards were of slate with 30-amp. type B switches, mounted in iron boxes, with wooden doors and trim. The switches were of Cutter manufacture and the receptacle of the flush wall type and of Pringle manufacture. The wire was rubber-covered and of the National Electrical Code standard.

The shop cost as shown by the contract ledger was $400.75, the cost items being as follows:

Materials	$254.36
Labor	136.74
Car fare, etc.	9.65
Shop cost	$400.75

TABLE XLIII. LABOR PER FOOT OF WIRE FOR INSTALLING EXPOSED KNOB-AND-TUBE WORK *

Size of wires, B. & S.	Running wire after backboard or buttons are erected	Erecting backboard or buttons
14	$0.015	$0.02
12	0.015	0.02
10	0.015	0.02
8	0.017	0.025
6	0.02	0.03
5	0.02	0.035
4	0.023	0.04
3	0.025	0.045
2	0.03	0.05
1	0.035	0.06
0	0.035	0.07
00	0.04	0.08
000	0.045	0.09
0000	0.045	0.10

* When good knob-and-tube work is installed in new and old buildings the labor at outlets will be practically the same as given in Table XXII under the several headings, and the labor for switches and receptacles should be exactly the same as in Table XXI.

The residence had thirty-two light outlets, twenty-eight switch outlets and twenty receptacle outlets. The cost of a switch plus the labor of installing it was $1 and the cost of a receptacle plus the labor of installing it was $1.10.

If all outlets were light outlets, the shop cost would have been approximately $400.75 — [(28 × $1) + (20 × $1.10)] or $350.75. Dividing $350.75 by the total number of outlets, which is 80, $4.38 is obtained. Hence $4.38 is the cost of wiring per light outlet. The cost of wiring a switch outlet is $4.38 + $1, or $5.38, and the cost of wiring a receptacle outlet is $4.38 + $1.10, or $5.48.

This method is fairly accurate for small-residence work, and any number of costs per outlet may be compiled to cover the various types of wiring construction, wiring systems, etc.

TABLE XLIV. LABOR COST PER FOOT FOR INSTALLING MOLDING

Wires			
Number	Size, B. & S.	Wood molding	Metal molding
2	14	$0.04	$0.08
2	12	0.05	0.08
2	10	0.06	0.08
2	8	0.07	...
2	6	0.08	...

* Metal molding is not made in sizes larger than for No. 10 wires, and wood molding is seldom used for wires larger than No. 6. The labor at outlets with molding is practically the same in the case of both wood and metal-molding construction. Tables similar to Tables XLII and XLIII can hence be made.

CHAPTER XIV

BELTS, SHAFTS AND MOTOR DRIVES

Cost of Split Pulleys. The costs of standard pulleys that can be used upon shafts of different sizes by the aid of interchangeable bushings are given in Table I. One pair of bushings is furnished with each pulley.

TABLE I. STANDARD IRON SPLIT PULLEYS

Diam., ins.	Face in ins. 4	6	8	10	12	14
6	$1.95	$2.15	$2.60	...	...	...
8	2.10	2.35	2.80	...	...	...
10	2.25	2.60	3.10	$3.45	...	...
12	2.70	3.00	3.70	4.10	...	...
14	2.90	3.30	4.00	4.50	$5.60	...
16	3.10	3.55	4.35	4.85	6.00	$6.90
18	3.35	3.85	4.70	5.30	6.55	7.60
20	3.80	4.80	5.80	6.45	8.00	9.00
22	4.10	5.15	6.20	7.00	8.65	9.80
24	4.85	6.00	7.35	8.25	10.20	11.45
28	5.65	6.95	8.55	9.75	12.05	13.40
32	6.95	8.60	10.60	12.10	15.15	16.75
36	7.95	9.85	12.05	13.80	17.15	13.95

Cost of Belting for Power Purposes. The following are costs of various types of belting:

Leather. Price per 1-in. width per running foot in cts.: Single, 9½ cts.; Double, 19 cts.; Triple, 28 cts. Weight; 16 ozs. to 1 sq. ft. in single ply.

Round Leather. Price per ⅛-in. width per running foot in cts.: Solid, 1½ cts.; Twist, 2 cts.

Cut Lacings, bundles. Price per ¼-in. width per 100 ft., 60 cts.

Rubber. Price per 1-in. width per running ft. in cts.

2-ply	3½ to 4½ cts.	6-ply	7½ to 9½ cts.
3-ply	4½ to 5 cts.	7-ply	9 to 11½ cts.
4-ply	5½ to 6 cts.	8-ply	10½ to 13 cts.
5-ply	6½ to 8 cts.		

The price increases as the width.

Stitched Canvas. Price per 1-in. width per running ft.

4-ply	3 cts.	8-ply	6 cts.
5-ply	4 cts.	10-ply	7½ cts.
6-ply	4½ cts.		

Detachable Link Belts. We give below a table of various sizes of detachable link belt with prices, etc. Figure the working strain

at one-tenth the ultimate strength for speeds of from 200 to 400 ft. per min. For lower speeds increase this by two-thirds. When a number of attachment links for fastening on buckets, etc., are used, add about 15% to cost of chain.

TABLE II. COST AND STRENGTH OF DETACHABLE LINK BELTS

Width, ins.	Number of links in 10 ft.	Ultimate strength	Price per ft.
¾	133	700	$0.04
15/16	104	1,100	.04
15/16	86	1,190	.04
1 1/16	86	1,300	.04
1⅛	74	1,200	.04
1 3/16	88	1,500	.05
1¼	74	1,600	.04
1⅛	104	1,900	.07
1 7/16	80	2,300	.07
1 5/16	74	2,200	.06
1 11/16	52	2,800	.07
1 9/16	73	3,100	.09
1¾	60	2,600	.09
1 5/16	52	3,300	.09
2	46	4,000	.10
2⅛	52	3,600	.10
2½	46	4,900	.14
2 15/16	30	4,950	.14
3 13/16	30	7,600	.18
2½	46	5,750	.17
2⅞	30	7,500	.20
4⅛	30	8,700	.21
3 1/16	39	9,600	.27
4 1/16	20	6,900	.20
4⅝	25½	9,900	.26
5 1/16	25½	12,700	.30
3 5/16	37	11,000	.34
5½	20	15,000	.45
3⅞	30	12,700	.42
5¼	20	14,000	.41

TABLE III. COST OF STEEL SHAFTING

Diam., ins.	Weight per ft., lbs.	Price per ft.
1	2.66	$.073
1⅛	3.36	.0925
1¼	4.16	.114
1⅜	5.05	.139
1½	6.00	.15
1⅝	7.04	.176
1¾	8.16	.204
1⅞	9.39	.235
2	10.65	.265
2⅛	12.07	.302
2¼	13.49	.337
2⅜	15.07	.377
2½	16.68	.417
2⅝	18.32	.457
2¾	20.18	.505
2⅞	22.09	.55
3	24.06	.625
3⅛	26.09	.668
3¼	28.24	.742

Diam., ins.	Weight per ft., lbs.	Price per ft.
3⅜	30.43	.797
3½	32.64	.897
3⅝	35.20	.967
3¾	37.45	1.03
4	42.50	1.28
4¼	48.26	1.44
4½	54.11	1.76
4¾	60.88	1.98
5	67.50	2.36
5¼	73.58	2.58
5½	80.72	3.02
5¾	88.24	3.68
6	96.25	3.85

Cost of Adjustable Shaft Hangers. Adjustable shaft hangers come in several standard sizes or drags: 8, 10, 12, 14, 16, 18, 20, 24, 30 and 36 ins., each having about 2 ins. adjusting distance.

The drag is the distance between base and the center of bearing.

TABLE IV. STANDARD BEARINGS

Diam. shaft, ins.	Standard sizes, ins.	Cost of 8-in. hangers	Approx. additional cost for each increase in size
15/16	8–14	$1.90	$0.10
1 3/16	....	1.95	.10
1 7/16	8–20	2.45	.12
1 11/16	....	2.50	.15
1 15/16	8–24	3.40	.15
2 3/16	8–36	4.35	.20
2 7/16	8–36	4.65	.20
2 11/16	8–36	5.40	.35

Selection of Economical Belts and Pulleys. (W. R. Schaphorst in Power, April 28, 1914.)

In a prominent factory in the city of New York there is an engine that runs 75 r.p.m., transmitting 100 h.p. from a 5-ft. pulley to a 4-ft. pulley. The distance between centers is 25 ft. Because of the slow engine speed and the relatively small driving pulley the belt has caused considerable trouble by slipping. Its velocity is less than 1,200 ft. per min., but a velocity of 3,000 ft. per min. would not be too high.

A 10-ft. driving pulley and an 8-ft. driven pulley would give the same final speed, and there would be less tendency of the belt slipping, because of the greater belt contact. The cost of the larger pulleys plus the cost of the correspondingly smaller belt required would be about $270.

Large pulleys should always be used, wherever possible, and especially if they can be proved most economical by the method cited.

In the factory mentioned a 40-in. belt is used. By doubling the diameters of the pulleys the belt speed is doubled and its transmission capacity is increased two-fold. A belt only one-half as wide, or 20 ins., would, therefore, suffice and its cost would be but one-half as great. The cost of the pulleys would be greater than in the present plant, but that increased cost would be more than

counterbalanced by the decreased cost of the belt; $270 could be saved, and the transmission defects would be eliminated.

TABLE V. ECONOMICAL BELT WIDTHS AND PULLEY SIZES

Diam. small pulley, ins.	Diam. large pulley, ins.	Width of belt, ins.	Length of belt, ft.	Cost of belt	Cost of small pulley	Cost of large pulley	Total cost
48	60	40	64	$1023	$179	$253	$1455
60	76	32	67.7	867	187	288	1342
72	90	27	71.2	769	239	346	1354
84	106	23	74.7	687	211	299	1197
96	120	20	78.25	627	234	324	1185

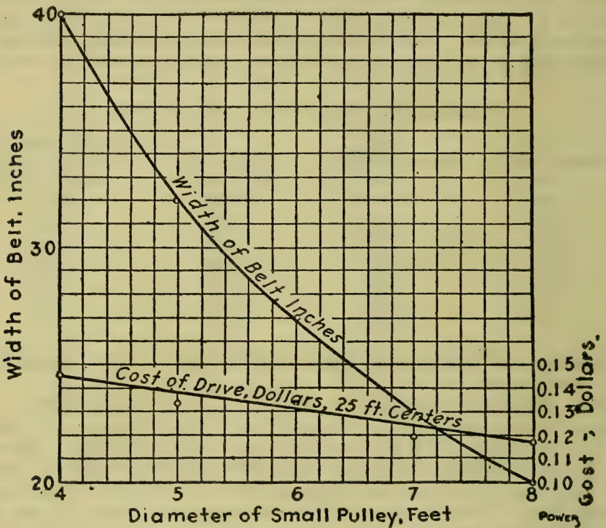


Fig. 1. Developing 100 h.p., speed of driving pulley 75 r.p.m.

In belt computations the rules that are most widely used are as follows:

Rule 1. A single-ply belt 1 in. wide, running 800 ft. per min. will transmit 1 h.p.

Rule 2. A double-ply belt 1 in. wide, running 500 ft. per min. will transmit 1 h.p.

To convert rule No. 1 into a formula applicable to most ordinary conditions, let

W_1 = Width of single-ply belt in ins.
W_2 = Width of double-thickness belt in ins.
H = Horsepower to be transmitted;

D = Diam. of driving pulley in ft.;
N = Revolutions per min. of driving pulley;
πDN = Speed of belt in ft. per min.;
$\frac{\pi DN}{800}$ = Horsepower a single thickness belt 1 in. wide will transmit.

Therefore,

$$W_1 = H \div \frac{\pi DN}{800} = \frac{800\,H}{\pi DN} = \frac{254\,H}{DN} \qquad \text{(I)}$$

By the same process rule No. 2 becomes

$$W_2 = \frac{159\,H}{DN} \qquad \text{(II)}$$

Adhering to the speed conditions laid down by the factory mentioned, a small pulley 5 ft. in diam. and a 6.25-ft. driving pulley would effect practically the same final speed. Applying formula (II) it is found that a 32-in. belt would be needed. Next, 6-ft. and 7.5-ft. pulleys with a 27-in. belt could be used.

It is most convenient to tabulate these figures in Table V with the length of the belt, the cost of the belt, and the costs of the pulleys. The total costs are then readily determined and compared. Plotting the total costs and belt widths, as in Fig. 1, the decreases in both are plainly shown.

The costs of pulleys and belting used in all of these tables are taken from the catalog of a manufacturer of transmission machinery and may be considered reliable for the problems solved here. Although, in this factory problem, the constant decrease in cost with increase in pulley diameters indicates that even larger pulleys might be still more economical, the curve could not be continued in this case because the limiting diameter of standard iron pulleys made by the manufacturers is 10 ft. Special pulleys would undoubtedly cost too much to be considered.

TABLE VI. ECONOMICAL BELT WIDTHS AND PULLEY SIZES. (Fig. 2)

Diam. pulley, ins.	Width of belt, ins.	Length of belt, ft.	Cost of belt	Cost of pulleys	Total cost
8	10	42	$109	$10	$119
12	6½	43	67	12	79
16	5	44⅙	53	12	65
20	4	45⅙	43	13	56
24	3¼	46¼	36	15	51
28	2¾	47⅓	31	18	49
32	2½	48⅓	29	21	50
36	2¼	49½	27	24	51
40	2	50½	24	37	61
44	2	51½	25	42	67

Table VI and curves in Fig. 2 show that where 10 h.p. is to be transmitted from a shaft making 400 r.p.m. to a second shaft 20 ft. away, making 400 r.p.m. also, 28-in. pulleys and a 2¾-in. single belt would be most economical. The cost curve in this case is almost flat from the 20-in. pulley size to the 36th-in. pulley size

and the designer is allowed a wide range of choice, but it should be remembered that large pulleys generally give least trouble from slipping. The belt speed of 3,000 ft. per min. with 28-in. pulleys

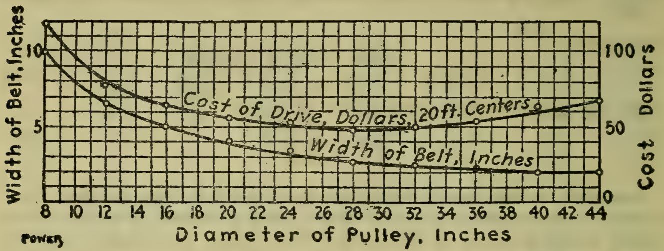


Fig. 2. Ten h.p., speed of driving and driven pulleys 400 r.p.m.

is not excessive and may be allowed without question. Formula I was used in computing the belt width in this and the other curves and tables.

TABLE VII. ECONOMICAL BELT WIDTHS AND PULLEY SIZES. (Fig. 3)

Diam. small pulley, ins.	Diam. large pulley, ins.	Width of belt, ins.	Length of belt, ft.	Cost of belt	Cost of small pulley	Cost of large pulley	Total cost
6	24	4½	64	$69	$3	$ 9	$81
7	28	3¾	64½	58	3	9	70
8	32	3	65⅙	47	3	11	61
10	40	2¾	66½	44	3	18	65
12	48	2¼	67⅚	37	4	24	65
16	64	1¾	70½	30	5	39	74
20	80	1½	73	26	6	..	..
24	96	1¼	75	23	8	109	140
28	112	1	78⅓	19	9	...	..

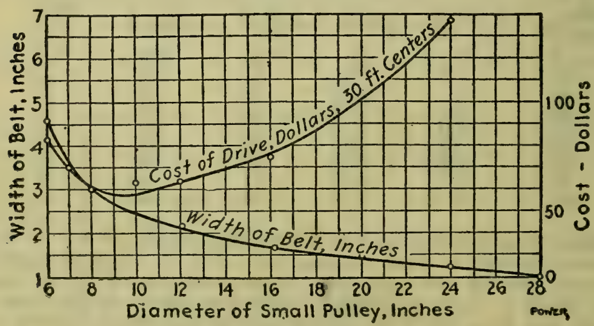


Fig. 3. Ten h.p., large pulley 300 r.p.m., small pulley 1200 r.p.m.

Fig. 3 shows the least expensive combination where 10 h.p. is to be delivered from a pulley making 300 r.p.m. to a smaller pulley making 1,200 r.p.m. Distance center to center is 30 ft. A small pulley 9 ins. in diameter, a 36-in. driving pulley, and a 2¾-in. belt will do very well. The computed results from which these curves were plotted are given in Table VII.

Table VIII and Fig. 4 (upper curve) and Table IX and Fig. 4 (lower curve) show that the best sizes are not always dependent

TABLE VIII. ECONOMICAL BELT WIDTHS AND PULLEY SIZES. (Fig. 4, Upper curve)

Diam. pulley, ins.	Width of belt, ins.	Length of belt, ft.	Cost of belt	Cost of pulleys	Total cost
16	19	64⅙	$293	$31	$324
20	16	65⅙	250	33	283
24	13	66¼	204	37	243
28	11	67¼	177	41	218
32	10	68⅓	164	41	205
36	9	69⅓	150	48	198
40	8	70⅓	135	46	181
44	7	71½	120	53	173
48	6½	72½	113	60	173
52	6	73½	106	54	160
56	5½	74½	99	62	161
60	5½	75⅔	100	70	170
72	4½	78⅙	85	100	185

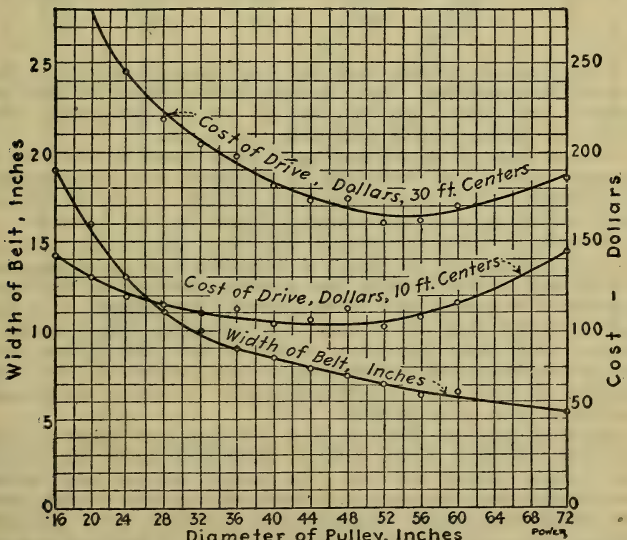


Fig. 4. Twenty h.p., speed of driving and driven pulleys 200 r.p.m.

upon the distance between shaft centers. The upper cost curve shows that where driving and driven pulleys are the same size, where the speed is 200 r.p.m., where 20 h.p. is to be transmitted and where the distance between centers is 30 ft. 52-in. pulleys and a 6-in. belt would be most economical. The lower cost curve is based upon the same conditions with the exception that the distance between centers is shortened to 10 ft. Although this shortens the belt considerably the plotted point on the curve nevertheless indicates that 52-in. pulleys and a 6-in. belt are again most desirable as regards first cost.

TABLE IX. ECONOMICAL BELT WIDTHS AND PULLEY SIZES. (Fig. 4—Lower curve)

Diam. pulley, ins.	Width of belt, ins.	Length of belt, ft.	Cost of belt	Cost of pulleys	Total cost
16	19	24 1/6	$110	$31	$141
20	16	25 1/6	97	33	130
24	13	26 1/4	82	37	119
28	11	27 1/4	72	41	113
32	10	28 1/3	68	41	109
36	9	29 1/3	63	48	111
40	8	30 1/3	58	46	104
44	7	31 1/2	53	53	106
48	6 1/2	32 1/2	51	60	111
52	6	33 1/2	48	54	102
56	5 1/2	34 1/2	46	62	108
60	5 1/2	35 2/3	47	70	117
72	4 1/2	38 1/6	42	100	142

It is therefore evident that the determination of pulley sizes need not be guesswork. After plotting curves similar to these the designer can exercise his judgment to the best advantage. This method is simple, requires little time, and is sure.

Friction Load of Shaft Bearings. From tests by Prof. C. C. Thomas made at the University of Wisconsin and given in Electrical World, Oct. 9, 1915, some data on performances of different kinds of bearings were formulated, as shown in Figs. 5 and 6.

The data in the accompanying table show the friction load due to shaft bearings and belt drives in the punch-press, screw-machine, drilling and tapping, milling and profiling, rough-store, tool-room, polishing and buffing, and initial-assembly departments of a new manufacturing plant in Indiana. The machines driven handle a product which weighs less than 10 lbs., so that the friction losses are an important consideration in the total energy demand. The shafting is supported in ball-and-socket, two-point, double-arm, ring-oiled, 24-in. drop hangers.

The data given in Table X were obtained from readings of a recording watt-hour meter, with all of the belts up to idle pulleys left running during the test. The results indicate that belting back from a main-line shaft to a sub-shaft increases friction losses and that it is better to install separate motors to drive such sub-shafts. It is also apparent that the number of bearings and the speed of the shaft have but little effect on the friction losses.

Liquid grease costing 10 cts. per lb. or $40 per bbl. was found satisfactory for all line-shaft and counter-shaft bearings and loose pulleys except those running at very high speeds.

Determination of Possible Saving. The curves of Fig. 6 have

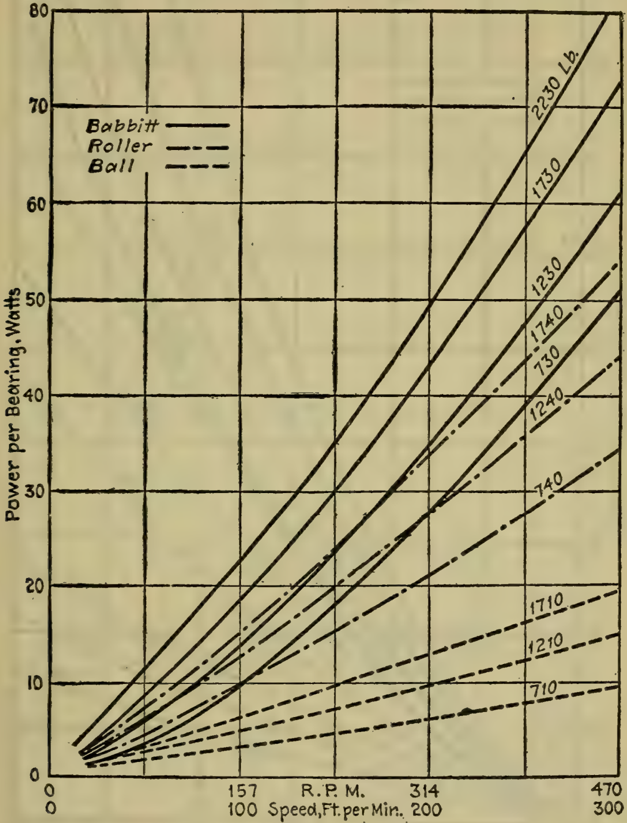


Fig. 5. Power consumed by friction of bearings with different loads and speeds. Temperature 77 degs. F.

been plotted to show the reduction of power consumed by ball bearings over ordinary bearings of the sleeve type. The data from which the curves were plotted were secured by using a motor under the same conditions to drive a long shaft equipped first with ring oiled babbitt bearings and second with ball bearings. Read-

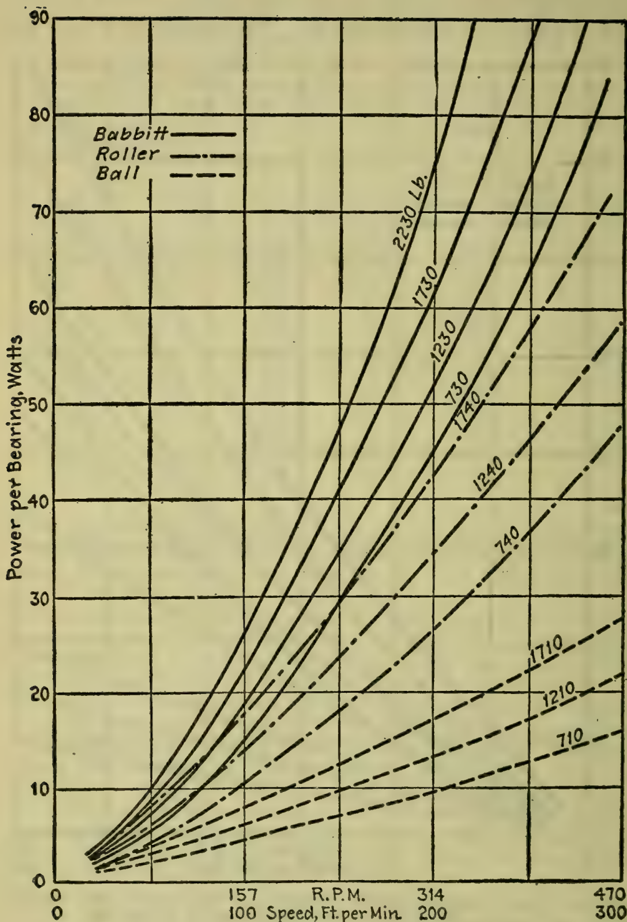


Fig. 6. Power consumed by friction of bearings at different loads and speed. Temperature 100 degs. F.

TABLE X. LINE SHAFT FRICTION LOAD IN A MANUFACTURING PLANT AS SHOWN BY TESTS.

Department	Line shafts										
	No.	Length in ft.	Diameter, inches	Speed, r.p.m.	Number of hangers	Number of countershaft bearings	Total number of bearings	Number of machines driven	Friction load in h.p.	Friction per bearing in h.p.*	Friction per machine in h.p.†
Punch press	1	160	2.6875	150	16	4	32	20	3.42	0.107	0.171
	2	120	2.1875	150	12						
Screw machine	1	150	2.6875	200	15	36	90	29	6.83	0.076	0.235
	2	170	2.6875	200	17	22					
Drilling and tapping	1	80	2.1875	200	8	18	49	17	2.28	0.046	0.134
	2	70	2.1875	200	7	16					
Tool room	1	90	2.4375	200	9	34	46	17	3.42	0.075	0.201
	2	20	2.1875	200	3	..	..	..	....	....	....
	3	90	2.4375	200	9	30	39	15	1.14	0.029	0.076
Milling and profiling	1	100	2.4375	200	10	20	30	10	2.28	0.076	0.228
	2	100	2.4375	200	10	22	32	11	3.42	0.107	0.311
Rough-store	1	20	2.1875	150	3	2	5	3	1.17	0.234	0.390
Polishing and buffing	1	60	2.4375	300	7	4‡	19§	9	10.25	0.540	1.140
Initial assembly	1	70	2.1875	200	8	24	32	12	1.51	0.063	0.125

* Includes belt losses. † Includes all losses. ‡ A 30-in. exhaust fan was running under load during test. § Includes 6 loose pulleys and 1 fan bearings.

In the punch-press, screw-machine and drilling and tapping departments a motor is belted to No. 1 shaft, which belts back to shaft No. 2. In the milling and profiling, rough-store, polishing and buffing and initial-assembly departments a motor is belted to each line shaft. In the tool room the motor is belted to shaft No. 1, which is a main shaft, and back to No. 2, which is a sub-shaft. Shaft No. 3 is driven by another motor.

ings were taken of the energy consumed by the motor under varying loads and speeds.

TABLE XI. SAVING EFFECTED IN ONE PLANT BY BALL-BEARING HANGERS

	Plain-bearing hangers	Ball-bearing hangers
Total kw. to operate machines and shafting	93	74.6
H.p. to operate shafting with belts on loose pulleys	32	13.5
Number of bearings	110	110
Cost of energy at 1.5 cts. per kw.-hr., for 3,150 hrs. per year	$4,394.25	$3.524.85
Cost of ball bearings, including erection	....	1,208.00
Interest on investment at 6%	....	72.48
Depreciation at 4%	....	48.32
Total cost first year	....	1,328.80
Saving in energy required	....	869.40
Saving in maintenance and lubrication	....	125.75
Total annual saving due to hangers	....	995.15
Return on investment after sixteen months, in per cent.	....	75.0

Steel Belts for Power Transmission. The efficiency of flat steel bands for the transmission of power has been investigated recently at the Technische Hochschule in Charlottenburg. The results show a remarkably high slip efficiency 99.5% and a striking economy in both first and operating costs over rope and leather-belt transmission. An abstract of a report of the results of the tests is contributed by J. P. Schroeter to Engineering News.

" According to the official tests made at the Technische Hochschule with steel-bands 23 mm. wide and 0.3 mm. thick, the useful tension per centimetre of width was 15 kg. with pulleys 1.250 mm. in diameter having a peripheral velocity of 15 m. to 30 m. per sec.; the useful tension was 10 kg. for pulleys 600 mm. in diameter running at a peripheral velocity of 15 m. per sec. The pulleys had a thin cork cover and the tension was very carefully adjusted to the most favorable conditions. Expressed in English units, these results may be summarized as follows:

	I.	II.
Belt width, ins.	0.906	0.906
Belt thickness, ins.	.0118	.0118
Pulley diameter, ins.	49.21	23.62
Peripheral speed, ft. per sec.	50 to 100	50
Effective pull per in. of width, lbs.	84	56
Effective pull per sq. in. of cross section, lbs.	7,112	4,742

" In practice there has been transmitted, with a steel-band of the above size, 145 h.p.; and, with one 100 mm. wide, 250 h.p.

" There is practically no noise either at high or low velocity, and in the tests it was impossible to find any elongation of the band. Its lightness and high tensile strength permit its use at higher velocities than are permissible with belts, and its use with generators and motors has proved very successful.

"An item not generally given enough consideration in calculations is the power lost in transmission. The accompanying table gives the first cost, efficiency and operating expenses with steel-bands and belt transmission."

TABLE XI. FIRST COST, FRICTION LOSSES AND OPERATING EXPENSES FOR STEEL-BAND TRANSMISSION OF 100 HORSE-POWER

First cost	Rope	Leather	Steel
Pulleys	$177	$96	$60
Belting	148	310	180
Total	$325	$406	$240
Losses.			
Loss %	13	6	0.5
Loss in h.p.	13	6	0.5
Loss per annum in h.p.-hrs.	39,000	18,000	1,500
Money loss	$663	$306	$25
Yearly expenses.			
5% interest on first cost	16.25	20.30	12.00
10% depreciation on pulleys	17.70	9.60	6.00
20% depreciation on belting	29.60	62.00	36.00
Friction loss as above	663.00	306.00	25.50
Total yearly	$726.55	$397.90	$79.50

NOTE.— Diameter of pulleys, 3.28 ft.; distance between axles, 32.8 ft.; cost per h.p.-hr., 1.7 cts.; 200 r.p.m.

Use of Steel Belts for Power Transmission. According to Engineering and Contracting, Jan. 1, 1913, steel belts have been used during the past year in some of the large manufacturing plants at Huddersfield, England, and have proved satisfactory. It is found that a 7⅞-in. steel belt, weighing 119 lbs., does the work formerly done by a leather belt 22 ins. wide, weighing 814 lbs., driving 300 h.p. In another mill a 3½-in. steel belt, weighing 12 lbs. does the work of a leather belt 12 ins. wide, weighing 64 lbs., driving 40 h.p. The steel belt saves space, does not slip or stretch and gives greater efficiency of power delivery. Tests have shown a saving of 61 h.p. on a drive of 640 h.p.

Steel Driving-Belts Compared with Rope Driving. In Lancashire (England) mills driven by ropes, shafting and belting, it is stated in Engineering Magazine, May, 1914, that the power losses between prime mover and machines vary from 25 to 35% of the total power generated. From 5 to 12% of the engine-power is wasted in hauling several tons of ropes round the rope-race. Hitherto it was thought that steel belts could only be used for light powers, but at the present time steel-belt drives of from 10 to 3,650 h.p. are in use, textile drives lying well within these limits.

The Eloesser steel belts are made from a specially hardened charcoal steel, prepared by a secret process, the finished material, it is stated, having a tensile strength of 95 tons to the sq. in., so that the length of each belt is constant, and no subsequent readjust-

ment is required. The thicknesses vary, but do not exceed 1 mm., and the widths are from 1½ ins. to about 8 ins., according to the working conditions and the maximum horse-power to be transmitted. The rims of the pulleys are covered with a layer of canvas, to which is glued thin sheets of cork.

TABLE XII. INDICATED HORSE-POWER OF THE STEAM-ENGINE

	With ropes h.p.	With steel belts h.p.	Saving in h.p.
Running with friction load (5 drives with ropes changed for steel belts) ..	342.2	318.1	24.1
The main shaft only of the above drives with full load	642.9	581.3	61.6

In connection with the investigations being undertaken by the mill-driving committee of the Textile Institute, a paper was read in Manchester on "Steel-Belt Power Transmission." The lecturer, Mr. Kruger, gave some details of comparative tests that had been carried out. The table shows a comparative test between ropes and steel belts, as a method of transmission.

The lecturer explained that at a spinning-mill, ropes transmitting 900 h.p. from a first to a second-motion shaft had been displaced by steel belts. The indicated power on the rope-drives for the two weeks previous to the conversion was 1,015 to 1,024, or a variation of 9 h.p. After steel belts were installed it was 898 h.p., or a clear gain over the ropes of 126 h.p.

Turning to smaller installations, the lecturer gave particulars of an interesting test of efficiency of steel-belt driving made on a 35 h.p. motor-drive. The current was supplied at 410 volts. The motor was tested without the belt, and absorbed 7 amps. Next the motor was belted up on to a short counter-shaft carried on ball-bearings, the motor-pulley, 13 ins. in diameter, running at 710 r.p.m. on to the counter-shaft pulley, 35 ins. in diameter. The belt was 7 ins. wide. The difference made in running the belt and the light counter-shaft caused the ammeter to register 7.75 to 8 amps. A further leather belt, 3 ins. wide, was then put on to drive the line-shaft from the counter-shaft from a 25-in. pulley on to a 73-in. pulley. This belt was only capable of transmitting 8 h.p. The increased power consumed measured on the ammeter raised the figure to 9 to 9.5. On taking the leather belt off and putting the steel belt on the same identical pulleys, the ammeter in circuit only registered 8 to 8.5 amps., showing a reduction in current required of 1 amp. as against the leather belt, which is equivalent to a gain of 12½% in efficiency over the leather belt.

As regards width occupied, this, of course, varies with the power to be transmitted, but one 8-in. belt in one instance replaces ten 2-in. ropes, in another case four 6-in. steel belts replace twenty-two 2-in. ropes, the horse-power transmitted being in the latter case 900. As the result of a series of experiments made for the most desirable tension in steel-belt driving, the frictional coefficient

between these belts and covered pulleys was found to equal 0.27. This value is practically equal to that of leather belts and iron pulleys. In Germany a number of rolling-mills have adopted the steel-belt drive.

Formula for Cost of Electric Motors. A. A. Potter in Power, Dec. 30, 1913, gives the formulae of costs given in Table XIII.

TABLE XIII. COST OF ELECTRIC MOTORS

Type	Capacity	Equation of cost in dollars
Direct-current, belted	Up to 1.5 h.p. (1400 to 2500 r.p.m.)	18.53 + 42.37 × h.p.
Direct-current, belted	1.5 to 30 h.p. (1000 to 1800 r.p.m.)	53.3 + 12.4 × h.p.
Direct-current, belted, upper limit	30 to 100 h.p. (500 to 800 r.p.m.)	191.7 + 10.94 × h.p.
Direct-current, belted, lower limit	30 to 100 h.p. (800 to 1000 r.p.m.)	213 + 8.264 × h.p.
Variable speed	Up to 10 h.p.-upper limit.	64.1 + 36.786 × h.p.
Variable speed	Up to 10 h.p. lower limit.	69.2 + 10.56 × h.p.
Alt. cur., single-phase (110–220 volts)	Up to 25 h.p. (1200 to 1800 r.p.m.)	25 + 11.75 × h.p.
A.c. belted polyphase induction	Up to 130 h.p. (1200 to 1800 r.p.m.)	116 + 4.72 × h.p.
Variable speed	Up to 25 h.p.	60.7 + 7.15 × h.p.
Variable speed	30 to 60 h.p.	157.6 + 3.573 × h.p.

Direct Current Motors. The weights and prices in Tables XIV to XVII have been derived from catalogue and appraisal data in our possession. The weights and prices for machines up to 75 h.p. and 75 kw. are largely taken from the catalogues and price lists of several well known manufacturers of this equipment. There is a variation of some 15% above and below the average price given and variation of about twice this amount is found in the weights.

TABLE XIV. DIRECT CURRENT MOTORS

Size in h.p.	Weight in lbs.	Price f.o.b. factory
	300 R.P.M.	
5	1,480	$ 295
7.5	1,980	370
10	2,450	440
15	3,280	560
20	4,000	660
25	4,750	760
50	7,800	1,160
75	10,050	1,510
100	13,000	1,840
150	17,500	2,380
200	21,500	2,650
250	25,200	3,320
300	28,700	3,750
350	32,000	4,100
400	35,500	4,500
450	38,500	4,850
500	41,500	5,200

Size in h.p.	Weight in lbs.	Price f.o.b. factory
	500 R.P.M.	
1	335	$ 100
2	530	138
3	700	169
4	860	195
5	1,000	220
7.5	1,350	275
10	1,680	325
15	2,250	415
20	2,750	490
25	3,250	560
50	5,450	840
75	7,250	1,090
100	8,900	1,300
150	12,000	1,710
200	14,800	2,050
250	17,500	2,400
300	20,000	2,660
350	22,200	2,980
400	24,300	3,200
450	26,500	3,500
500	28,800	3,750
	1,200 R.P.M.	
1	218	$ 67
2	300	92
3	385	110
4	465	127
5	545	140
7.5	720	171
10	890	200
15	1,200	250
20	1,480	295
25	1,730	335
50	2,850	500
75	3,830	630
100	4,750	760
	1,800 R.P.M.	
1	185	$ 55
2	245	76
3	300	92
4	360	105
5	410	116
7.5	545	142
10	670	152
15	890	200
20	1,100	235
25	1,320	270
50	2,130	400
75	2,850	505
100	3,520	600

TABLE XV. ALTERNATING CURRENT MOTORS

(Two and 3 phase, 25 cycle for 110, 220, 440 and 550 volts.)

Size in h.p.	Weight in lbs.	Price f.o.b. factory
	750 R.P.M.	
1	140	$ 275
2	150	290
3	155	325
4	165	360
5	170	390
7½	190	470

Size in h.p.	Weight in lbs.	Price f.o.b. factory
10	215	530
15	270	660
20	330	760
25	390	860
50	680	1,275
	1,200 R.P.M.	
1	180	$ 43
2	240	60
3	360	74
4	380	88
5	460	98
7½	650	125
10	830	145
15	1,150	190
20	1,500	230
25	1,750	270
50	2,600	425

TABLE XVI. ALTERNATING CURRENT INDUCTION MOTORS
(Two and 3 phase, 60 cycle, for 110 to 220 volts.)

Size in h.p.	Weight in lbs.	Price f.o.b. factory
	500 R.P.M.	
1	130	$ 30
50	160	48
75	190	57
100	220	65
125	250	70
150	280	82
200	350	100
250	420	115
300	480	130
350	550	145
400	600	160
450	680	175
500	750	185
	900 R.P.M.	
1	130	$ 28
2	135	32
3	140	35
4	142	38
5	145	40
7½	155	46
10	165	50
15	195	60
20	230	68
25	270	78
50	450	120
75	640	160
100	800	200
	1,200 R.P.M.	
1	155	$ 46
2	195	60
3	250	74
4	310	88
5	360	100
7½	500	135
10	620	165
15	875	215
20	1,150	270
25	1,400	310
50	2,500	515

Size in h.p.	Weight in lbs.	Price f.o.b. factory
	1,800 R.P.M.	
1	145	$ 40
2	165	50
3	200	60
4	230	68
5	270	78
7½	360	100
10	450	125
15	610	165
20	800	200
25	1,000	235
50	1,800	380

TABLE XVII. TURBO-DRIVEN EXCITERS

Size in k.ws.	Weight, in lbs.	Price f.o b. factory
	3,600 R.P.M.	
25	3,850	$1,320
35	4,100	1,425
50	4,700	1,650
75	5,850	2,080
100	7,400	2,550
	2,500 R.P.M.	
25	4,200	$1,430
35	4,700	1,650
50	5,700	2,040
75	7,900	2,700
100	10,500	3,350

Cost of Changing 2-Phase Induction Motors to 3-Phase. A small central station in the West described in Electrical World, May 11, 1912, changed its entire distribution system from 2-phase to 3-phase, retaining the original frequency of 60 cycles. This made it necessary to rewind all 2-phase motors connected to the system. There were 10 of these motors, ranging from 2 h.p. to 25 h.p., all operating at 220 volts.

TABLE XVIII. COST OF REWINDING POLYPHASE INDUCTION MOTORS

Motor	Labor	New coils	Miscel-laneous	Total
25 h.p., 1200 r.p.m.	$11.92	$45.00	$2.64	$59,56
15 h.p., 1200 r.p.m.	19.08	21.32	3.52	43.92
10 h.p., 1200 r.p.m.*	24.07	16.82	4.44	45.33
5 h.p., 1800 r.p.m.	3.56	....	0.82	4.38
5 h.p., 1800 r.p.m.	2.40	....	0.63	3.03
5 h. p., 1800 r.p.m.	2.40	....	0.62	3.02
5 h.p., 1800 r.p.m.	2.40	....	0.51	2.91
3 h.p., 1800 r.p.m.*	7.47	....	1.68	9.15
3 h.p., 1800 r.p.m.	1.60	....	0.40	2.00
2 h.p., 1800 r.p.m.	3.78	....	0.68	4.46

* Extra time was required owing to errors in blueprints.

The winders received 40 cts. per hr. and their helpers from 34 cts. to 42 cts. per hr. The motors were of two standard and well-known makes. In two instances the labor costs were excessive,

as noted in the table, because the connections as shown on the manufacturer's blueprints were in error. The motors of 10 h.p. and larger were rewound with new coils, while those of 5 h.p. and less were reconnected. The grand total cost was $177.76 for 10 motors with a combined rating of 78 h.p. or $2.28 per h.p.

Cost of Individual Electric Drive. In a paper and discussion before the National Association of Box Manufacturers at a recent convention, F. M. Kimball and L. R. Pomeroy emphasized a number of points which have a direct bearing upon the general problem of electric driving. One point especially was the ease with which a check can be kept upon the condition of the tools or machines when driven by d.-c. motors. Wood-working tools, in particular, when out of alignment or carrying dull cutters, may easily absorb 200% more power than they normally require, and this excess power is not only wasted, but is absorbed in friction and strains which are damaging to the machine. Under such conditions the niceties of adjustment are disarranged and the machine is liable to permanent injury. By placing an indicating wattmeter in circuit with the motor and observing its reading when the driven tool is known to be in perfect adjustment and alignment, with the cutter in good order, and comparing that reading with subsequent readings from time to time, an abnormal use of power is at once made known, and corrective measures may be applied in time to prevent serious injury.

Mr. Pomeroy presented the following results from 8 cases of electric driving:

The difficulty of having at hand figures showing the direct advantage of the motor drive in dollars and cents, as applying to wood-working shops, is explained by the fact that so far, everyone adopting the electric operation of tools has taken opportunity at the same time to enlarge and improve the plants so that no direct comparison with previous conditions can be made. The following figures may have a relative bearing:

1. Operation — boring a cylinder.

Total time,	730 mins.
Less helper's time,	215 mins.
Net time,	515 mins.

Actual time cutting, 225 mins., or 43.5% — over 50% non-productive time. If only 10% of this time could be saved, it would result, for a $4 per-day man, in $120 per annum, which capitalized at 10% is $1,200. The logic of this is that we could afford to spend $1,000 if only 10% saving could be effected. A motor would save more than this in increased efficiency alone. The particular tool in the case would require a motor costing about $120. Add to this the proportion chargeable to the motor for power plant, i. e., $140, and we have $260.

2. A certain shop located at Richmond, Va., installed an aggregate of 1,510 h.p. motors. The average load is 30%, or 450 h.p. An engine-and-belt system could easily use up this amount

in friction alone. The friction load is constant and is as much when one h.p. of work is being done as when the plant is carrying full load. Per contra, with motor drive, the friction load is that of one motor — if only one is in operation — and the others in proportion. The friction load in machine shops runs from 40 to 80% of the original power developed by the engine.

3. The annual cost for belting, for maintenance and repairs, amounts to 37% of the initial cost each year. F. W. Taylor says that the average annual cost equals $6.90 per double belt per annum; say on an ordinary 40-ft. double belt 8 ins. wide, costing $30, the average charge amounts to $11 or 37% of $30.

4. Mr. Harding, speaking of the Carnegie works at Duquesne, says that the intermittent operation of motors is carried from a central station by means of one-sixth the h.p. required when individual engines were used.

5. Another large plant formerly driven by 30 separate engines, because of widely scattered buildings, saved 40,000 lbs. of coal in 24 hrs. by adopting an electric drive from a central plant. A test from one department of this plant under the old conditions showed that the line shafts and loose pulleys consumed 61.75 h.p., or 30%; machines and counter shafts, 141 h.p., or 61%; machines cutting at normal rate, 210 h.p.

6. Mr. Vauclain, in discussing the electric drive in the Baldwin Locomotive Works, made the following statement:

The application of electricity in the frame shop resulted in a reduction of the force of 60%; while in the wheel shop the discarding of the shafting enabled the placing of one-third more wheel lathes on the same floor space. The electric traveling crane superseding the hand jib cranes reduced the common labor from 40 to 6 men, with 50% saving in power. Electricity was first introduced to drive two 100-ton cranes, resulting in an immediate saving of 80 men of the laboring force, a saving of 20% in pay roll, and 40% in shop area for a given product. Crane installation cost about $65,000. Sixty-five to 75 men would equal this amount in each year.

7. Belt drive as applied to most machines does not permit of running the tool to its limit, on an average job, while direct motor-drive does.

8. The C., M. and St. P. Ry. installed a motor on a turntable costing $550, which resulted in a wage saving of $1,600 per year.

The statement having been made that the expense for fuel in a box factory was nil, owing to the waste and shavings being utilized, figures were presented for the cost of power, entirely eliminating the fuel question on the basis of a 100 h.p. plant:

	Per h.p. per year
Labor, 2 men, engineer and fireman	$21
Water at 10 cts. per 1,000 gal.	4
Repairs	5
Removing ashes	5
Interest and depreciation	6
Total per horse-power year	$41

Two cents per k.w.-hr. at same rate (10-hr. day) amounts to \$45 per h.p.-year.

Steam Engine vs. Motor Drive for Small Machine Shops. A. G. Popcke in Electrical Journal, Aug., 1910, discusses the advantage of electric drive over steam drive and gives examples showing the saving actually effected in two instances.

A Shop Driven by a Single 25 h.p. Motor with an average recorded load of 10 k.w.: The various machines in the shop were subsequently divided into separate motor-driven groups without attempting to improve the arrangement of counter-shafts. The grouping and results obtained are shown in Table XIX.

TABLE XIX. GROUP DRIVE

Groups of Machine tools	Motor: H.p. rating	Motor: Kw. load	Operation: Hours per day	Operation: Kw.-hrs. per day
Lathes	3	2	14	28
Lathes	3	2	6	12
Drills and lathes	3	2	14	28
Milling machine	3	2	9	18
Planer and milling machine	5	2	10	20
Total	17	10	..	106

The two groups of lathes are operated 14 hrs. per day; hence, when the shop was driven by a single motor the total energy required was $10 \times 14 = 140$ k.w.-hrs. When group drive was installed only 106 k.w.-hs. were required, that is, the saving is 34 k.w.-hrs. per day. Assuming the power rate at three cts. per k.w.-hr., and 25 working days per month, the saving effected by the small group drive is $0.03 \times 34 \times 25 = \$25.50$, or \$306 per year, a large percentage of the total operating expenses of a small shop.

Engine-Driven Belt Transmission Replaced in a Small Machine Shop by Motor Drive and Electric Power purchased from a local central station: The shop manufactured brass fittings and the character of the manufactured product was not changed, consequently the operating expenses before and after the substitution of electric drive afford a fair basis of comparison of the relative merits of the two systems. The original equipment consisted of a 12 h.p. steam boiler and a small engine driving the line shafting. A man, who tended the boiler and engine and did some other work, was employed for \$2.50 per day; \$1.50 of this amount was fairly charged against the operation of engine and boiler. The coal bill amounted to \$25 per month. The boiler was discarded and the engine replaced by a 7.5 h.p. electric motor, with the result that the total power bills now range from \$37 to \$42, averaging approximately \$40 per month. The yearly expenses for power with engine and with motor drive were as follows:

Engine Drive:

Coal per year (12 × \$25)	\$300
Attendant (312 days at \$1.50 per day)	468
Total	\$768

Motor Drive:

Power bills (12 × $40)	$480
Difference favoring motor drive	$288

A 7.5 h.p. motor costs approximately $200; that is, the motor saves more than its first cost every year, thereby paying dividends of over 100%. Excepting the few repairs necessary, this saving goes on during the life of the motor, which is ordinarily many years.

Cost of Motor Drive in a Six-Story Factory. The power plant serving the building described in Electrical World Aug. 23, 1913, contained two 200-h.p. Stirling boilers and two Harrison boilers housed in a boiler room measuring 60 ft. by 75 ft. Hand-firing was employed and the two Stirling boilers, operated at 150 lbs. steam pressure and 100 degs. superheat, were equipped with an automatic fan arranged to reinforce the draft when it fell below a fixed value. The Harrison boilers were much older, and were used only for heating purposes and for operating an elevator pump. In the engine room, measuring 24 ft. by 56 ft., there was installed about ten years before the test a 20-in. by 42-in. Rice & Sargent simple non-condensing engine, delivering about 200 h.p. at 90 r.p.m. Its exhaust was led to a feed-water heater which raised the feed temperature to 176 degs. F., none of the exhaust being returned again to the boiler. Power was transmitted to the six floors of the building by means of belting and jack shafts. On each floor friction clutches were placed between the line and jack shafts, to permit disconnecting a part of the equipment on the floor when desirable.

Plans for Electrical Operation. In taking up the electrical operation of the installation three different plans were considered. The first was to install one motor of about 300 h.p. rating to drive the entire mill; the second was to employ individual drive, and the last, to use a group plan of drive. The first was deemed impracticable since the space occupied by the jack shafts and belting would not be available for manufacturing purposes, and since the loss in the jack shafts, which was found to be about 25% of the total load, would not be eliminated. The second plan would have necessitated costly changes in the arrangement of line shafting and called for the abandonment of most of it, besides tending to cause serious interruptions in the operation of the machines. The group-drive plan was considered best for the building, since it would result in no interruption in the service and would eliminate jack shafts and jack-shaft belting.

In order to determine what sizes of motors would be needed on the different floors a 30-h.p. motor was set up to drive the separate line shafts and the input noted by a Westinghouse curve-drawing wattmeter. As a result of these tests it was decided to install fifteen three-phase, 230-volt induction motors to drive the departments concerned, the total rating being 4,380 h.p.

Before the steam plant was removed, opportunity was offered

to secure data on the operation of the shop by steam. The load on the engine was found by taking indicator cards at frequent intervals throughout three days. Two tests on the steam plant were made, one with the Stirling boilers supplying the engine alone and one with the boilers supplying the auxiliaries and engine. The object of the first test was to obtain the efficiency of the engine and boilers, and of the second to secure data as to the amount of coal and water usd in the boilers to supply steam to the auxiliaries and engine.

Methods of Power Measurement. In order to obtain roughly the power delivered to each of the six floors the following method was used: With all the floors in operation indicator cards were taken at the engine; then the sixth floor was thrown off by means of the clutch connecting the line to the jack shaft and cards were again taken. The difference between the two engine h.p. readings was then assumed to be the power delivered to the sixth floor, plus the friction losses due to the transmission to that floor. Then the clutch was again thrown in and the operation repeated for the other floors in turn. The engine efficiency was found to be 10.12% and the boiler efficiency 54.3% in the tests above referred to. The buckwheat coal used cost $3.60 per net ton and was found to contain 12,100 B.t.u. per lb.

With all the machines idle, and with only the shafting load on the engine, the output of the latter was 163.4 i.h.p. The power required to drive the jack shaft, or in other words the shafting and belting from the engine to the clutches on the various floors, was 78.4 h.p. The total power delivered to the floors, according to data obtained by throwing out each floor in succession, was 223.4 h.p. This, added to the power required to drive the jack shafts, aggregated 301.8 h.p.

DETERMINATION OF COST OF STEAM POWER

Hours of running:

(Plant is shut down two weeks for repairs.)	
50 weeks at 5 days of 10 hours and 1 day of 5 hours, less 6 holidays, gives per year, in working hours..	2,690
Coal used per year in tons, including 119 tons for banking (5 lb. per brake-h.p. per day)............	1,664
Water per year, in thousands of gals...............	2,338

Operating Costs:

Water per year at 20 cts. per 1,000 gals.............	$467.60
Oil and waste at 0.033 cts. per h.p.-hr.	259.40
Ash removal, 399 tons at 25 cts. per ton.............	99.80
Coal per year at $3.60 per ton	5,980.00
Repairs at 2% of investment (see below)..........	339.00
1 engineman, 50 weeks at $18........................	900.00
1 assistant engineman at $15........................	750.00
1 fireman at $12	600.00
Total operating cost with steam	$9,395.80

Investment Cost and Fixed Charges:

Two 200-h.p. Stirling boilers (at $13 per h.p.)......	$5.200.00
Feed pump and heater	850.00
Piping	2,000.00

20-in. x 42-in. simple non-condensing engine	8,000.00
Stack, at $2.25 per boiler h.p.	900.00
Total investment	$16,950.00

Fixed Charges:

Interest at 5% on $16,950	$847.50
Profit, 10% on $16,950	1,695.00
Insurance and taxes, 2%	339.00
Amortization of boiler, 1.5%, 30-year life	108.00
Amortization of auxiliaries, 3%, 20 years	25.50
Amortization of engine, 1.5%, 30 years	120.00
Amortization of stack, 0.5%, 50 years	4.50
Total	$3,139.50
Grand total steam cost per year, operating expenses and fixed charges	$12,545.30

DETERMINATION OF ELECTRICAL COST

Cost of Motors:

3 50-h.p. motors 900 r.p.m., at $450.00	$1,350.00
2 35-hp. motors, 1,200 r.p.m., at $360.00	720.00
2 25-h.p. motors, 1,200 r.p.m., at $301.50	603.00
3 20-h.p. motors, 1,200 r.p.m., at $277.20	831.60
2 15-h.p. motors, 1,200 r.p.m., at $233.10	466.20
1 10-h.p. motors, 1200 r.p.m. at $201.60	201.60
2 5-h.p. motors, 1,800 r.p.m., at $71.10	142.20
Total, less 10% discount	$3,883.10

(Cost of motors included starting compensators, with motors in service, excluding wiring.)

Cost of wiring	$200.00
Total cost of electrical installation	4,083.10

Fixed Charges, Electrical Installation:

Interest, 5% on $4,083.10	$204.20
Profit, 10% on $4,083.10	408.30
Insurance and taxes, 2%	81.70
Depreciation, including repairs and obsolescence, figured at 10%	408.30
Total	$1,102.50
Energy consumption of installation per year, on basis of energy supply to mill directly from central-station mains, requiring 538,650 kw.-hr. at 2 cts.	$10,733.00
Fixed charges	1,102.50
Total cost of electrical service	$11,875.50
Net saving by use of electric drive, $669.80.	

In this installation the survey indicated that the usual labor economies of the electric drive could not be assumed for the reason that without the complete electrification of the factory group as a whole the existing force would probably be retained. Electricity has been installed in the six-story building, however, and has introduced substantial improvements in the operating conditions, notably in connection with the release of highly valuable real estate for manufacturing purposes and the facilitation of overtime work through subdivision.

Electrification of Shops of Wabash Railroad. At Moberly, Mo.,

several small boilers and engines at the shops and the pump house were replaced at comparatively small expense by one station with a 150-k.w. generator for shop tools, light and pumping, as described in Railway Age Gazette, Feb. 3, 1911. A similar installation has been made at the Wabash shops at Fort Wayne, Ind., and Springfield, Ill.

At Springfield the power is furnished by outside parties and is delivered at 2,300 volts. It is transformed by Westinghouse oil type transformers to 440 volts for power purposes and 110 volts for lighting. Westinghouse oil type circuit breakers are used at the switchboard on both the power and lighting circuit, and in addition there are three-pole, single throw, no arc, fused knife switches protecting each circuit. All wiring is in conduits. The main machine shop and the erecting shop have six motors as follows: Two 35-h.p., one 25-h.p., one 20-h.p., and one 15-h.p. driving the machine tools and one 25-h.p. motor on the drop table. The tools in the machine shop annex are driven by a single 20-h.p. motor. A 7½-h.p. motor is used for driving the carpenter shop and a 20-h.p. motor in the boiler and blacksmith shop. For furnishing blast for the boiler and smith shops a 35-h.p. motor is used direct connected to a 12-in. fan. All motors, with the exception of the one operating the drop table are of the three-phase 440 volt, 60 cycle, a.c., induction or squirrel cage type. The drop table motor is a slip ring type with a reversible controller which furnishes variable speed from 850 to 1,140 r.p.m.

Power is furnished by the Springfield Heat, Light & Power Company, which brought the power wires to a convenient point in the shop yard and installed a transformer at its own expense. The aggregate power of the 10 motors is 177½-h.p., and the cost of the installation was as follows: Ten motors, $2,838; pulleys and belts, $264.54; switches, $70.55; conduit and wire, $332.64; switchboard, $82.59; sundries, $163.49; labor, $350; total, $4,101.81. The estimated cost of the transformer furnished by the power company was $350.

Power Required to Drive Shafting, B. R. & P. Ry. We have taken the following from an article published in The Ry. and Eng. Review, Feb., 1908:

These tests, in addition to furnishing accurate data relating to the power required for various tools when starting, running light, and cutting, also make possible some examination of the merits of roller bearings for shaft hangers. The line shafts are cold-rolled steel carried on Hyatt roller bearings, and a shaft 200 ft. long without belts can be turned by hand. But in spite of the unusual efficiency of the bearings, it will be noted that the power consumed by the tool is often less than that lost in transmission. Nevertheless, the capacity in motors required for the group is two to two and a half times smaller than it would have been had each tool been provided with an individual motor.

It is a question as to how far the low average power taken by large groups of tools in operation may be due to the flywheel action of the shafts and pulleys.

The locomotive-erecting, boiler, and machine shop consists of a middle aisle for erecting and two shed bays equipped with shafting for driving the machine tools. Two 50-ton, electric traveling cranes have a runway in the middle aisle. There are five lines of shafting driven by the five shunt motors in the shed bays, and the sections are designated as wheel section and boiler section in one bay, and the lathe, tool, and flue sections in the opposite bays.

Wheel Section. Shafting driven by a 40-h.p. shunt-wound motor and operating:

42-in. car-wheel boring mill
48-in. car-wheel lathe
Two 79-in. wheel lathes
Quartering machine
60-in. by 60-in. by 18-ft. planer
84-in. boring mill
Single axle lathe
6-ft. radial drill
18-in. slotter
Band saw
No. 7 grinder
Water tool grinder.

The line shaft is 200 ft. long, 2½ ins. in diameter, and has 26 hangers. It was inconvenient in this instance to obtain a test of the line shaft alone. A test of the line shaft and counters only gave 1.5 horsepower.

The speed of the line shaft was 160 r.p.m.

Boiler Section. Shafting driven by a 30-h.p., shunt-wound motor and operating:

12-ft. bending rolls
Bolt-cutter
Staybolt cutter
Drill press
Tool grinder
Brooks plate planer
Horizontal punch
Shear and punch
6-ft. bending rolls
6-ft. straightening rolls
6-ft. radial drill.

All the counter belts were thrown off and the line shaft tested alone, with a result of .3 h.p. This line shaft is 170 ft. long, 2½ ins. in diameter, and has 19 hangers. The speed of the line shaft was 158 r.p.m.

A test of the line shaft and countershafts, only, gave an average of 2 h.p.

Lathe Section. Shafting driven by a 30-h.p., shunt-wound motor and operating:

24-in. crank planer
36-in. by 36-in. by 20-ft. planer
51-in. boring mill
16-in. shaping machine
24-in. drill press
37-in. boring mill
Two 22-in. lathes
Three 16-in. lathes
Two 18-in. lathes
28-in. lathe
43-in. lathe
2-in. by 24-in. flat turret lathe
Milling machine
Grinding machine
Three 18-in. turret lathes
24-in. drill press
28-in. lathe
No. 10 vertical milling machine
Two spindle rod drills
14-in. pillar shaper
16-in. lathe
26-in. by 26-in. by 6-ft. planer
32-in. drill press
Surface grinding machine
Water tool grinder.

The line shaft and counters required 2.8 h.p. The line shaft is 140 ft. long, 2½ ins. in diameter, and has 20 hangers. It was not convenient to obtain a test of the line shaft alone. The speed on the shaft was 155 r.p.m.

TABLE XX. DATA ON TOOLS AND MOTORS

Five polishing jacks One 50-lb. trip-hammer One shear One blower	Shaft speed 300 r.p.m. One 23-in. pulley	5-h.p. motor 1,700 r.p.m. 4-in. by 4-in pulley
Two 7-in. stones 125 r.p.m. 30-in. pulley	Shaft: One 30-in. pulley One 12-in. pulley	10-h.p. motor 1710 r.p.m. 6-in. by 5-in. pulley
Two 75-lb. trip hammers 325 r.p.m. 13-in. pulley	Shaft: One 12-in. pulley One 7½-in. pulley	5-h.p. motor 1,700 r.p.m. 4-in. by 4-in. pulley
Three 16-in. lathes One 18-in. lathe One 24-in. lathe One 12-in. lathe Two speed lathes One 20-in. upright drill One sensitive drill Two shapers One planer One milling machine	Shaft: 125 r.p.m. One 22-in. pulley Countershaft: One 30-in. pulley One 8-in. pulley	7½-h.p. motor 1,710 r.p.m. 6-in. by 5-in. pulley

The line shaft of the lathe and tool sections can be connected by a clutch coupling and the whole operated from either motor.

Blacksmith Shop. The blacksmith shop machinery is driven by a 40-h.p. shunt-wound motor, which is belted to 75 ft. of 2½-in. line shafting with 12 hangers. The apparatus driven comprises a volt header, a 25-in. punch and a shear, a cutting-off saw, a tool grinder, a 40-in. planer, a drill press, a 50-lb. hammer, a blower and an exhaust fan.

A test of the line shaft and counters with grindstone and two blowers constantly in operation gave 14.5 h.p.

The Cost of Electric Drive in a Foundry is given by Electrical World, Sept. 13, 1913. The table gives the list of tools and motors required to operate them.

The total installation aggregates 27.5 h.p. of connected load, and the estimated monthly energy consumption is 1,328 k.w.-hr., giving a net bill of $49.17 per month for electricity. The average load is estimated at about 7 h.p. The present cost of operating the foundry by steam power is:

150 tons coal, at $4.75	$713
Engineer, 2 hrs. per day, at 25 cts. per hr.	150
288,000 gals. water, at 10 cts. per 1,000 gals.	28
Oil, waste, etc.	50
Ash removal	24
Taxes, insurance, depreciation, interest and repairs	135
Total ($91.50 per month)	$1,100

The first cost of motors is as follows:

One 5-h.p. motor	$72
One 10-h.p. motor	158
One 5-h.p. motor	72
One 7.5 h.p. motor	135
Total	$437

With the most liberal allowance for fixed charges and such steam-heating service as may be necessary after electric drive has been installed, there is indicated a decided saving by the use of central-station service.

Power to Drive Wood-Working Tools. Data on electric driving in wood-working shops were obtained in two installations in London. Both were the establishments of builders and contractors. The first plant was supplied with compound-wound motors at 460 volts, with Sturtevant starting rheostats, and the second with shunt-wound motors at 214 volts with Ward-Leonard motor starters. The records of the tests were reported in The Electrician, of London.

A circular saw, in the first plant, driven at about 1,000 r.p.m. by a 12-h.p. motor, took a 10-in. cut at the rate of 6 ft. per min. on 10 by 7-in. damp pitch pine, requiring 13.8 h.p. A tenoning machine driven at 2,700 r.p.m. by a link belt from a 5-h.p. motor, took 5.5 amps. running light and 9.5 amps. when tenoning pitch pine, removing 3½ cu. ins. of wood in 10 secs. A planer designed for 8 by 24-in. planks and driven from a 5-h.p. motor took 5.5 amps.

in making a ⅛-in. under cut in pitch pine 9 ins. wide, finishing a plank 8.5 ft. long in 25 secs. A ¼-in. over cut from a plank of pitch pine 5 ins. wide took 5.2 amps. in finishing a 6-ft. length in 20 secs. A band saw traveling at a speed of 4,800 ft. per min. required 2.4 amps. when the motor was driving the belts only, and 3.5 amps. when driving the belt and band saw running light. An emery wheel used for grinding tools and belt-driven at 1,640 r.p.m. by a ½-h.p. motor required 0.7 amp. when the outfit was running light; when grinding a straight moulding cutter the current ranged from 1 to 2 amps.

In the second plant a band saw driven by a 3.5-h.p. motor at a speed of 3,600 ft. per min. took 4.5 amps. when running light. When making a 6-in. cut in deal wood 9 amps. were taken and 2 ft. were sawed in 25 secs.; with a 2-in. cut in mahogany, 7.5 amps. were taken and 1 ft. was sawed in 4 secs.; with a 4¾-in. cut in oak, 10.5 amps. were taken and 1.5 ft. were sawed in 15 secs.; with a 2¾-in. cut in beech, 10 amps. were taken when 1 ft. was sawed in 15 secs. A 19-in. circular saw driven by a 7-h.p. motor at 1,050 r.p.m., required 7.5 amps. when running light. With deal wood the following figures were obtained: Two-in. cut, 6-ft. 2-in. length, 17.5 amps., 10 secs.; 1¼-in. cut, 4-ft. 2-in. length, 14 amps., 5 secs.; 1¼-in. cut, 7-ft. 3-in. length, 15 amps., 8 secs.; 6-in. cut, 2-ft. length, 18 amps., 20 secs. A planer, designed for 20 by 8-in. planks and driven by a 5-h.p. motor, took 15 amps. when making a 3/16-in. cut from a 9-in. wide deal plank, requiring 45 secs. for a length of 7 ft. 2 ins.; it took 16 amps. when making a 3/32-in. cut from an 18-in. deal plan, cutting 3 ft. 8 in. in 17 secs. A 6-in. emery wheel grinder driven at 1,860 r.p.m. from a 2½-h.p. motor took 2.5 amps. with motor and belts only, 4.5 amps. with the emery wheel light, and 5.5 amps. with the emery wheel grinding a moulding cutter.

Application of Electric Drive to Paper Calenders is described at length by E. C. Morse in the Transactions of the American Institute of Electrical Engineers, July, 1912. The pecularity of this service is that considerable power is required to drive the machines at a high rate of speed and it is necessary that the machines be operated at a much reduced speed when threading the paper through or when a tear or weak spot in the paper is encountered.

Comparisons of cost are given and the advantages and disadvantages of electric drive are discussed as follows:

Mechanical and Electrical Advantages and Disadvantages of Each Drive. In the following comparisons it should be remembered that the paper maker is primarily interested in cost of production. He is, therefore, interested in mechanical and electrical simplicity, ease of control and operation, small maintenance, minimum labor, minimum power cost per unit output.

It has been found from many tests and observations that calenders are run on slow speed from 25 to 33% of the time; 10 to 22% of the time is consumed in "threading in," varying with weight of paper or length of roll.

The following comparisons are bare statements of facts and

it is not the intention to recommend one drive over another. A large advantage for one drive, in some mills, may be insignificant in another.

Group Drive by Motor — for A-C. and D-C. Advantages. With this drive the manufacturer has a constant slow speed, only one motor and starter for entire group, minimum chance of trouble with electrical apparatus. Lower first cost, therefore lower fixed charge per calender.

A 70 in. calender arranged for drive from line shaft costs....	$4,600
Shaft per calender approx..........................	100
Share of capacity in large motor for 70 in. calender........	400
Total	$5,100

Disadvantages. Belts to maintain, two clutches to keep in repair; main shaft takes space on floor below calenders; friction clutch to throw in high speed and as usually operated there is a sudden strain on paper with consequent possibility of breaking and lost production. Only one high speed and no way to vary it. Large motor operating on a widely fluctuating load from 15% to 150% load which means poor efficiency, poor power factor, and a variation in the speed of shaft of 5% or more. It has also been found that the shafting and belting loss alone, per calender, is approximately four kws. This means for a 24-hour day, 96 kw.-hrs. at $0.01 per kw.-hr., $0.96 per day, $288 per year. This capitalized at 5% means $5,770.

Two-Motor Drive for D-C. and A-C. Advantages. Constant "threading in" speed, smooth acceleration from slow to high speed, reducing strains on paper and lost production. Ability to slow down to any desired point easily and quickly. Calender can be geared to run at maximum speed that any of paper will stand as slower speeds are available for weaker paper. This speed can easily be 10 to 15% higher than in the group drive. Only one clutch necessary and that a pin clutch. Sometimes a friction clutch is also used on large gear on slow speed so the pin clutch may be thrown in without starting the rolls and the rolls started by friction clutch. Both these clutches are operated from one lever. Large motor operated at good efficiency and power factor. Losses minimum on slow speed. The slow speed motor running light has an average input of 0.6 kw. This corresponds to the friction of the shafting in the group drive, as the large motor does not consume energy except when driving the calender at its operating speeds. Moreover, the efficiency of the motor in the group drive will be nearly the same as this large motor. It may be assumed that this 0.6 kw. is a 24-hr. loss, as the small motor is usually left running continuously and is used for "threading in" only 10 to 15% of the time. Thus 0.6 kw. for 24 hrs. per day at $0.01 per kw.-hr. = $0.144, or $43.20 per year of 300 days — a gain of $234 per stack over group drive or 5% on $4,700.

Good power factor is maintained on the line since the idle current of the small motor is small.

Disadvantages. High first cost: A 70-in. calender,

For two-motor drive	$4750.00
For small motor	170.00
For large motor	900.00
For control	300.00
Total	$6120.00

Maximum chance of trouble exists with electrical equipment. Large floor space is required. It requires three times as long to stop after power is shut off as group driven calender. Large motor requires the same kw. input regardless of speed, assuming constant torque. This disadvantage is more than overcome by increased production possible, due to variable speed feature.

Two Motors Replaced by One. Same for D-C. and A-C. Advantages. One less motor to care for than in two-motor drive. Less floor space required, constant "threading in" speed obtained, smooth acceleration from slow to high speed, ability to easily slow down if desired. Calender can be run at maximum speed any paper will stand, as slower speeds are available for weaker papers. As motor and gear may be disconnected from stack on stopping, the flywheel effect same as in group drive. If stack is stopped by cutting power off the motor the flywheel effect same as in two-motor drive.

Calender, 70 in., and mechanism	$4925.00
Large motor	900.00
Control	275.00
	$6100.00

Disadvantages. Two clutches, one being friction; large gear on quill which may wear and cause excessive gear wear. Requires same kw. input regardless of speed, assuming same torque. This is turned to an advantage by increased production possible. Light load losses larger. Based on a 70-in. stack, a three-phase 550-volt 75-h.p. motor running light will operate with a current approximately 2.5 amp., power factor 15 to 20% kw., input 4.0 to 6.0. Assuming 5 kws. to be average and the motor running light 20% of time or 4.8 hours per day, we have $5 \times 0.01 \times 4.8 = \$0.24$ per day or $72.00 per year, or $28.80 per year more than two-motor drive. This is 5% on $575 and small motor costs $170. The worst effect is in the power factor of the system if many of these motors are installed. As far as power consumed goes, there is ordinarily not much choice.

Single Motor, Direct Geared. Advantages. a-c. Only one motor is used, no clutches, minimum possible amount of gearing and smallest floor space of all drives. The calender can be geared for maximum speed that any of the paper will stand and can be easily retarded at will, and operated at slower speeds for weaker paper. Smooth acceleration from "threading in" to running speed is obtained. The first cost is lower:

Calender	$4185
Motor	900
Control	450
Total	$5535

Additional Advantages on d-c. Dynamic braking can be used to stop calender quickly. More stable "threading in" speed due to the fact that full field speed is about ⅓ maximum and the speed has to be further reduced by armature resistance to ⅓ or ¼ instead of ⅛ or 1/12 as with a-c. Losses are less on reduced speeds than with a-c.

Disadvantages. Very unstable "threading in" speed is obtained; controller setting usually has to be changed during "threading in." Extra large controller and resistance is required to obtain the slow speed. The large flywheel effect causes the calender to run three times as long as if group driven. It has been found on this type of drive that the "threading in" requires from 9 to 14% of total time and on a 72-in. calender the power consumed varied from 16 to 29.8 kws. during this period, as against about 2.2 to 4 kws. with two-motor drive. As this time required to "thread in" is also somewhat longer, the cost of power used for the "threading in" process is from 6 to 10 times that of the other two types of drive. This motor is practically never running except when paper is in the calender, and therefore has no "running light" loss to correspond to the other drives. The power factor is low while motor is running light and during "threading in." The control for this drive is subjected to the hardest service of all, as 60% to 100% full load current is broken every time the current is shut off. Motor tests show that the current is broken 13 to 15 times per hr. as an average. This means for a 24-hr. day, six-day week, 1,870 to 2,160 breaks per week. The ordinary circuit breaker contact is said to be good for about 3,000 breaks, so a very substantial switch must be used in order to get any reasonable length of service. This drive may require more labor, or in other words a third man may be needed at controller during "threading in." This same man can, however, take care of several stacks.

From the preceding pages certain advantages of motor driven supercalenders have been pointed out which tend to lower cost per unit product and to increase the production per machine. These may be summarized as follows:

a. Long mechanical transmissions eliminated with maintenance of their shafts, belts, hangers, etc.

b. Reduced chance of all calenders being shut down at once. With mechanical drive this often happens, due to belt breaking or shaft trouble, and the loss of production is large.

c. Smooth acceleration from slow to high speed, reducing strains on paper, therefore reducing breakage and loss of production.

d. Ability to operate calender at maximum speed which the particular paper will stand. With group drive only one speed is available.

e. Ability to easily slow down for a weak place in paper saves much time and increases production. At one point paper ran 25 minutes without a break but the controller was used 26 times to reduce the speed and it is further seen that it requires on the average three to five minutes to paste together the paper and feed it in again. If the paper had broken 13 times only it would mean

$$\frac{13 \times 4 \times 500}{3} = 8700 \text{ yds. of production lost.}$$

f. The speed of calender is much more likely to be uniform, as in group drive the number of calenders operating varies the belt slip and speed of line shaft.

g. The kw.-hrs. per unit output required are less than in group drive.

h. The power factor of system is better than when large motor drives group, if a two-motor drive is used.

i. That the above facts are true is proved by figures of one of the largest and best managed mills in the United States which give the average efficiency of all motor-driven calenders as 35% better than group driven and of two of the most recent drives, 50% better.

Electric Motors on a Farm. Electrical World, Aug. 3, 1912, states that six miles from Dayton, Ohio, on a large estate use has been made of electricity supplied over a 3-phase, 6,600-volt transmission line from the Dayton company. A 15-h.p. motor mounted, with its starter, on a portable truck can be moved about the place to drive a corn husker, shredder, wood saw and thresher. Another 3-h.p. motor drives a deep-well pump, delivering the water supply for the estate to a reservoir on the hilltop. A ½-h.p. motor pumps cistern water, and the laundry is equipped with a motor-driven mangle. This year it is planned to install electric irrigation on a large scale to intensify the output of the soil, and later experiments will be carried out with electrification to stimulate plant growth.

Tests were recently made at the farm to determine the power required and energy input for various farm operations. For example, it was shown that 1,750 bushels of barley could be threshed at an expenditure of 220 kw.-hrs., the maximum demand being 20.5 kws. In this Montgomery County section steam-thresher hire costs $20 a day.

In a series of 10-min. tests to learn the power required by a corn grinder running idle, it was found that the motor alone consumed 0.106 kw.-hr., and the motor and grinder 0.341 kw-hr., leaving 0.235 kw.-hr. chargeable to the idle grinder, or an average demand of 1.41 kws. Three tests were then made of the energy consumed in the operation of grinding corn, with the results tabulated, Table XXI.

In the third test the corn was husked directly from the shocks and was still damp, so that excessive power was required, as shown.

TABLE XXI. ENERGY USED IN GRINDING CORN

	Dry corn	Damp corn
Bushels ground	46.17	12.00
Time, min.	68.	21.
Bushels per hr.	40.8	34.2
Kw.-hrs. per bushel	0.411	0.607

The same motor was also tested driving the shredder and husking machine, which running idle consumed 1.425 kw.-hrs. in ten minutes, or 1.319 kw.-hrs. for the machine alone, indicating an average input of about 8 kws. Fifteen hundred pounds of fodder was shredded in twenty-three minutes, consuming 4.03 kw.-hrs. This shows an energy consumption at the rate of 5.37 kw.-hrs. per ton, or 0.186 tons shredded per kw.-hr. The maximum kw. taken was 14.5 and the minimum 8.2, indicating an average of 10.5 kws. Nearly 40 tons of fodder are shredded yearly at the farm, the average cost of shredding which would be $3 a ton were the present electric appliances not used. The Dayton company built the pole line and furnished the transformers and meter for the installation, all other equipment being the property of the customer.

A Comparison of Gas and Electric Power for Drawbridge Swinging. We have taken the following from an article published in Engineering News, June 18, 1912:

The new steel swing span of the International Bridge over the ship canal at Black Rock, N. Y., erected in July, 1911, is one of the heaviest single-span bridges in the country, being 431 ft. 5 ins. long, and weighing 4,500,000 lbs. It carries a double track for steam trains besides a roadway for electric cars and pedestrian traffic.

The bridge is operated by electricity and can be swung in 70 secs. Two Westinghouse street-car motors are used for turning the span, each rated at 53 h.p. with ability to stand short overloads of 100%. There are two 15-h.p. end-lift motors and two of 5 h.p. for operating rail wedges. All are controlled from the operator's house above the bridge deck.

To supply current to these motors a small power station has been erected containing (1) a 100-h.p. Otto gas engine direct-connected to a 60-kw. d.c. Garwood generator, (2) a 60-kw. Garwood motor-generator driven by a 2,200-volt induction motor receiving current from a Niagara Falls power station, and (3) a 255-cell storage battery having a capacity of 60 amps. at the 8-hr. discharge rate.

One of the yard men visits the station at certain periods and ascertains from the switchboard instruments whether or not it is necessary to recharge the storage batteries. Any desired combination of generators and storage battery may be made; all may feed the bridge motors, giving 400 h.p. for a short time; one generator may be used for the bridge movements while the other is charging the battery. One man can easily start the gas engine.

Tests to find the power required for a day's operation were made on Sept. 3, 1911, with wind at a velocity of 4 miles per hour. The following data were secured, assuming ten 10-min. swings per day:

	Kw.-hrs.
Navigation, house and deck lights, 17 lamps, 16 c.p., 12 hours per day	52.0
Signal lights, 16 lamps, 8 c.p.	1.7
Rail wedges	2.2

	Kw.-hrs.
End lifts	0.7
Air compressor (operating latch, whistle and band brakes)	3.8
Turning motors	13.3
Total kw.-hrs.	73.7

Tests were made on Aug. 25, 1911, to find the cost of gas-engine power with a battery-charging load. The following data resulted:

Energy generated	108.4 kw.-hr.
Gas used	2608 cu.-ft.
Length of run	3 hr.

Costs:

Labor, 30 cts. per hr.	\$0.90
Oil, 40c. per gal.	0.20
Water, 2 cts. per M. cu.-ft.	0.12
Gas, 30 cts. per M	0.78
Total	\$2.00
" per kw.-hr.	0.0184

With a charge-discharge efficiency of 65% for the storage battery and 10 swings per day, the cost of gas power to the bridge motors would be

$$\$0.0184 \frac{73.7}{0.65} = \$2.09$$

For a year of 365 days the total cost would be

Interest, depreciation, repairs, etc., on gas-engine generating set (20%)	\$1300
Power	764
	\$2064

The cost of operation by Niagara Falls power was determined from tests made Aug. 31, 1911, with the motor-generator set charging the battery. The following data resulted:

Length of run	2 hr.
Output to battery	72 kw.-hr.
Input to motor	88 kw.-hr.
Efficiency of set	81.9%

The rate for Niagara power was given thus — at monthly rate:

Service charge	\$50.00
Up to 1000 kw.-hr.	0.020
1000 to 2000 kw.-hr.	0.015
Over 2000 to 3000 kw.-hr.	0.012
Over 3000 to 4000 kw.-hr.	0.010

With, as before, a demand on the motor of 113.5 kw.-hrs. per day and a motor-generator efficiency of 81.9%, the monthly bill would be for

$$\frac{113.5 \times 30}{0.819} = 4160 \; kw.\text{-}hr.$$

To find the resultant unit rate we take:

Service charge	$50.00
1000 at 2 cts	20.00
1000 at 1.5 cts.	15.00
1000 at 1.2 cts.	12.00
1160 at 1 ct.	11.60
	$108.60
Per kw.-hr. input	2.6 cts.
Per kw.-hr. to battery	3.2 cts.

With a charge-discharge efficiency of 65% for the battery and 10 swings per day, the cost of Niagara power alone would be

$$\$0.032 \frac{73.7}{0.65} = \$3.63$$

For a year of 365 days the total cost would, then, be summarized thus:

Interest, depreciation, repairs, etc., on motor-generator set (15%)	$ 590
Power	1,325
	$1,915

According to this there is practically no difference in the total cost of operating the bridge by one service or the other. It should be understood that both services have been provided for continuity of operation and the expected annual costs are then combinations of the foregoing figures.

Expected Annual Cost with Gas Power

Interest, depreciation, repairs, etc., gas-engine set (20%)	$1,300
Interest and depreciation on motor-generator set (7½%)	295
Power	764
Total	$2,359

Expected Annual Cost with Niagara Power

Interest, depreciation, repairs, etc., on motor-generator set (15%)	$ 590
Interest and depreciation, gas-engine set (10%)	650
Power	1,325
Total	$2,565

Cost Record of an Electric Power Shovel. (Electric Railway Journal, Jan. 23, 1909.)

Some accurate records of the cost of operating an electric power shovel used in digging ballast have been furnished this paper by the Chautauqua Traction Company, Jamestown, N. Y. The shovel, which was built by the Vulcan Steam Shovel Company, Toledo, Ohio, weighs complete about 40 tons and the car body on which it is mounted is 27 ft. long. The dipper has a capacity of 1½ cu. yds. The various movements of the shovel are made with three d.c. 600-volt motors, one of 75 h.p. for hoisting, one of 30 h.p. for

swinging the boom and one of 30 h.p. for crowding the shovel. These motors are protected from overloading by series overload relays, automatic controllers and circuit-breakers. In addition the swinging motor is fitted with a solenoid brake for overcoming the momentum of the boom and the crowding motor is equipped with a foot brake operated by the craneman.

The cost of power and help was as follows:

1 man	$0.33
1 man	0.25
2 men, at 15 cts.	0.30
20.346 kw.-hours at $0.0088	0.18
Oil and waste, estimated	0.04
Total cost per hour	$1.10
8 hours at $1.10	$8.80
8 hours at 66⅔ cu. yd.	534 cu. yd.
$8.80 divided by 534 cu. yd.	0.0164 cent

The material in which the shovel was worked was a mixture of gravel, sticky clay and sand, which made it hard to dig, but as will be seen from the above figures, the cost was very low. There are, of course, several causes for this, the principal ones being, first, that as the shovel required no boiler, the cost of a fireman and of hauling coal and water was eliminated; second, that the work of the shovel was intermittent and when the shovel was idle no power was being consumed, as would be the case with a steam shovel where steam must be kept up constantly. The shovel could have been operated to its maximum capacity, which would have given twice the yardage at nearly the same cost, as the men had to be paid whether they were working or idle, and the additional cost for power would not have been more than twice what it was, which on the same basis would mean 1,068 yds. at a cost of $10.24, or $0.01 per cu. yd.

Cost of Operating Motors in Lime Plants and Quarries. In a recent paper presented before the National Lime Manufacturers' Association printed in Electrical World, Aug. 12, 1916, R. D. Donaldson gave operating data and costs for motor drives in several lime plants and quarries. He called attention to the fact that although it is generally believed the application of an electric motor to a steam hoist requires either a d.c. motor or some type of variable speed a.c. motor, experience has shown that this is unnecessary, for the constant speed a.c. motor can be applied to practically all steam hoists. A complete new crankshaft for an existing steam-driven hoist and the necessary gears to reduce the speed as low as possible is all that is required. In regard to hoisting with an electric motor, one case was cited where approximately 3,000 tons of stone per month was hoisted up an incline with a total lift of approximately 115 ft. at a cost of $11.50 with current at 2 cts. per k.w.-hr.

The energy consumption of a stone crushing plant running fairly steadily and turning out 3,000 tons of crushed and screened stone per month was given as 1 to 1.1 kw.-hr. per ton. A plant running fairly steadily and turning out 12,000 tons of crushed stone

per month consumes between 0.8 and 1 kw.-hr. per ton of product. The idle load of a crusher plant is very large. The power required to keep the crusher plant running up to speed approximates 50% of the total power required to crush the maximum quantity of stone. By good routing of cars, however, or by any other means which will keep the operation of the crusher plant up to its maximum output, the power consumption per ton of stone crushed can be reduced from 30% to 40% from the consumption figures given.

The following data show the investment cost for electrifying and operating different lime plants.

TABLE XXII. COST OF EQUIPPING AND OPERATING LIME PLANTS

	Plant I	Plant II	Plant III
No. of kilns	5	4	16
Tons output for 24 hrs.	65	48	200
Cost of equipment	$5,000	$2,500	$ 1,500
Cost of energy at 2 cts. per kw.-hr.	4,000	2,400	12,500
Cost of steam operation	6,500	4,800	19,500
Annual saving	2,500	2,400	7,000

These plants operate the following equipment:

Plant No. 1. Two 200 g.p.m. centrifugal pumps, blower fan, 2 hoists, 50-h.p. crusher, fan, hammer mill, bagger, rotary mixer, Broughton mixer, hair picker and water supply pump.

Plant No. 2. Kiln blower, 2 hoists, 1 300-gal. centrifugal pump.

Plant No. 3. A 150-h.p. crusher plant, dust mill, hammer mill, two complete hydrating plants, Broughton mixer, bag cleaner, 5-h.p. quarry pump, small machine shop, hair picker, elevator, two kiln blowers, 30-h.p. air compressor for quarry drills. The total installed h.p. for this plant was 650.

Farm-Implement Manufacturing Power Requirements. (W. J. Kyle in Electrical Review and Western Electrician.)

The term load-factor is used in these data in such a sense that a load-factor of 100% represents the use for 24 hrs. every day of power corresponding to the rated capacity of the motors connected. An operating-time load-factor of 100% represents the use of the rated capacity of the motors for the running hours per day specified for each installation.

Company manufacturing power knives, reaper sickles, guard plates, lawn mowers, etc. There are 150 men employed working 10 hrs. per day.

Total connected h.p., 619. Total number of motors installed, 54. Average kw.-hrs. per month, 22,888.

Load-factor 6.8%; operating-time load-factor 15%.

The following is a list of the motors installed with their respective drives. The supply source is three-phase, 60 cycles, 440 volts. All motors, unless otherwise specified, are of the squirrel-cage induction type.

Eight 15 h.p., 850 r.p.m. Slip-ring motors, each belted direct to a grindstone. Stones average about 36 ins. diameter and 12-ins.

face. They are used to grind bevel on the cutting implements. Driving pulley 10 by 9. Driven pulleys 28 by 8 ins.

One 5 h.p., 1,120 r.p.m. Vertical motor coupled to an American Well Works vertical bilge pump. No. 2½, capacity 200 gals. per min., 3-in. suction and 2.5-inch discharge pipe vertically mounted with float chains and a Cutler-Hammer switch automatically starting and stopping motor. This pumps out the water and dirt from the well and the grindstones.

One 20 h.p., 690 r.p.m. Slip-ring motor, belted to a large grindstone used for beveling cutters. Stone is 72 by 12 ins. Pulley 9 by 9 ins. Driven pulley 42 by 8 ins.

Ten 15 h.p., 870 r.p.m. Slip-ring motors belted to 10 grindstones for beveling cutting tools. Stones vary in size between 48 by 14 and 72 by 14 ins. Pulleys 10 by 9 ins. Driven pulleys 20 by 8 ins.

Five 7.5 h.p., 1,120 r.p.m. Belted to five surface girders. Stones have grinding face (side) average about 30 ins. Pulleys 8 by 9 ins. Driven pulleys 24 by 8 ins.

One 20 h.p., 850 r.p.m. Belted to a surface grinder. Stone has a grinding face (side) of 36 ins. Pulley 8 by 9 ins. Driven pulley 24 by 8 ins.

One 5 h.p., 850 r.p.m. Belted direct to Williams White & Company No. 3 hammer.

One 7.5 h.p., 850 r.p.m. Belted to a Garden City blower No. 1. Pulley 6 by 10 ins. Driven pulley 24 by 8 ins.

One 10 h.p., 1,120 r.p.m. Belted to a 78-foot 10-hanger shaft driving four automatic-feed 76-link hardening machines and four hand-feed 76-link hardening machines. These machines are about 10 ft. long and the links each carry one piece to be hardened. It is driven by a chain and sprocket from the line shaft. Two 2-ft. by 3-ft. tumbling barrels. One 100 lb. drop hammer.

One 10 h.p., 1,120 r.p.m. Belted to a 50-ft. 7-bearing shaft driving one No. 3 Parker punch press, flywheel, 48 by 5 ins.; one scrap cutter; one small emery wheel; three machines for serrating sections; three guard-plate cutting machines; one A. Leggoe & Company machine for serrating special knives; one American Gas Furnace Company high-pressure blower; one Webster & Perks Tool Company section serrating machine; one section serrating machine; one emery wheel 14 by 2 ins.; one Pittsburgh counter-sinker; two Parker small punches, flywheels 24 by 3 ins.; one 30-ft. four-hangers shaft driving one small punch for guard plates; one E. W. Bliss Company automatic punch, No. 3 flywheel 38 by 5.5 ins.; one Pittsburgh Machine Works countersinker; one roller for straightening small bars; one Bliss punch, flywheel 36 by 5 ins., and one double emery wheel.

Two 3 h.p., 1,120 r.p.m. Backgeared and belted to two Bliss No. 4 blanking presses, flywheels 42 by 6 ins. One of these machines is located in the machine shop.

One 10 h.p., 1,700 r.p.m. Belted to a 36 ft. 5-hanger shaft driving one Bliss No. 5 punch, flywheel 46 by 6 ins.; one Bliss shear for cutting sections, flywheel 42 by 6 ins.; one Pratt & Whiting 12-in.

drill; two Stiles & Parkin presses No. 1, flywheels 26 by 3 ins.; one Pratt & Whitney 12 in. drill; one guard milling machine; one special punch, flywheel 48 by 5.5 ins.

One 3 h.p., 1,700 r.p.m. Belted to a riveting machine that will rivet three at a time, flywheel 36 by 5.5 ins.

One 1 h.p., 1,700 r.p.m. Belted to a small gasoline pump.

One 10 h.p., 1,120 r.p.m. Belted to a 45 ft. 7-hanger shaft driving one 16-in. Steptoe shaper; one Fox Machine Company No. 23 milling machine; one Danson & Goodwin 16-in. lathe; two E. W. Bliss No. 2 presses, flywheel 30 by 4 ins.; one special press, flywheel 27 by 3 ins., and one small screw machine.

One 10 h.p., 1,120 r.p.m. Belted to a 42-ft., 7-hanger shaft driving a Dietz, Gang & Company 24-in. lathe; one double emery wheel 4 by 0.5 ins.; one automatic tool sharpener; one Smith & Mills 16-in. shaper; one Knecht Brothers Company 12-in. drill; one Barnes 24-in. drill; two Q & C hack saws for 12-in. blades; one H. C. Pease & Company plane; one double buffing arbor, wheels 16 by 4 ins.; one small surface grinder, 7-in. wheel; one two-spindle drill; one Bliss No. 2 punch, flywheel 30 by 4 ins.; one two-spindle drill, 16 ins.; one special drill; one special surface-grinding machine; one grindstone 18 by 3 ins., grinds surfaces of cutters; one Rudolph's Krummel No. 4 punch, flywheel 26 by 6 ins.; and one machine carrying two sets of rolls for treating sections.

One 15 h.p., 1,120 r.p.m. Belted to a 72-ft. 10-hanger shaft driving one Pratt & Whitney 24-in. drill; one Barnes 18-in. drill; four Barnes 20-in. drills; one double emery wheel; one small fan about 12 ins. in diameter for a forge fire. There is also another centrifugal fan for exhausting the 6 or 8 emery wheels.

One 5 h.p., 1,120 r.p.m. Belted to a 50-ft. 7-hanger shaft driving one four-spindle Barnes drill press; one Barnes 28-in. drill; one Barnes 22.5-in. drill; one Kempsmith Manufacturing Company No. 32 plain miller; one Garvin Machine Company No. 2 plain miller; one Fox Machine Company No. 3 miller; and one milling machine.

One 10 h.p., 1,080 r.p.m. Belted to a 53-ft. 8-hanger shaft driving two double emery wheels, Northampton, 9 by 2 and 10 by 2 ins.; one double 16-in. buffer; one No. 1 Styles & Parker punch, flywheel 6 by 3 ins.; two double Northampton surface grinding wheels, 8-in. face, and one double emery wheel.

One 7.5 h.p., 1,150 r.p.m. Direct-coupled to shaft of drum of a 3,000-pound freight elevator at 50 ft.

Two 30 h.p., 1,120 r.p.m. Slip-ring motors belted to two automatic surface-grinding machines. Grinds the surfaces of the cutting tools Pulleys 15.5 by 9 ins. Driven pulleys 22 by 8.5 ins.

Five 7.5 h.p., 1,120 r.p.m. Belted to five hand-feed surface grinders. Grinders average about 28 ins. in diameter. Pulleys 8 by 9 ins. Driven pulleys 30 by 8 ins.

Two 2 h.p., 1,120 r.p.m. Belted to two finishing machines.

One 5 h.p., 1,120 r.p.m. Belted to a finishing girder for heavier work. Grindstone is 14 ins. by 3 ins. Driven pulley is 28 by 6 ins.

One 20 h.p., 850 r.p.m. Belted to a sickle grinder. This consists

of a stone about 42 ins. face or diameter across which the whole sickle is pulled and thus sharpened. Pulley 10 by 11 ins. Driven pulley 36 by 8 ins.

Two 15 h. p., 690 r.p.m. Slip-ring motors belted to two stones used both as a grinder to bevel the cutter and also to grind surfaces. Two men on each grindstone at a time, one nearly on top and one in front. Stones are 40 by 14 ins. Pulley 9 by 9 ins. Driven pulleys 30 by 8 ins.

The following is a comparison of the previous steam-plant costs with present costs of central-station service. An outline of the motor installation is given in the accompanying table.

TABLE XXIII. MONTHLY OPERATING COSTS STEAM PLANT
(Figures from books)

Engineman	$ 80.00
Fireman	50.00
Coal passer	50.00
325 tons of fuel at $1.50 per ton	487.50
Repairs to engine, boiler, valves, piping, boiler tube cleaning, etc.	110.00
Cylinder and engine oil	5.67
Boiler compound	17.00
Waste and packing	4.20
Total	$804.37

TABLE XXIV. RECORD OF ELECTRICAL OPERATIONS 260 HOURS PER MONTH

	Kilo-watts	Kilo-watt-hours
Tower shop, including all friction	12.3	3,198
Grinding room, eliminating friction	52.4	13,645
Machine shop, including friction	16.2	4,212
Ventilating fan	2.0	520
Small service pump	2.4	624
Factory lighting	20.0	700
Total		22,897

The cost of change to produce the above results was $5,895.

At the rate earned by the company the approximate saving in operating costs per month is 30%.

Power Used in a Small Implement Manufacturing Plant making a small line of farm and garden implements, such as hoes, rakes, garden plows, etc. There are 12 men employed, working 8 hrs. per day.

Total connected h.p., 89. Total number of motors installed, 12. Average kw.-hrs. per month, 2,730.

Kw.-hrs. consumption for 9 months: July 2,270, August 3,050, September 2,060, October 2,730, November 2,240, December 4,180, January 2,560, February 2,600, March 2,750.

Load-factor, 5.6%; operating-time load-factor, 14%.

The following is a list of the motors installed with their respective drives. The supply source is two-phase, 60 cycles, 220 volts.

One 50 h.p., 690 r.p.m. Belted direct to air compressor.

One 7.5 h.p., 1,200 r.p.m. Belted direct to Prentice engine lathe.

One 5 h.p., 1,200 r.p.m. Belted direct to one S. & M. two-spindle shaper.

One 5 h.p., 1,200 r.p.m. Belted direct to one Prentice 30-in. drill press.

One 2 h.p., 1,700 r.p.m. Belted to a Buffalo No. 3 forge blower; and one 12-in. emery wheel.

One 25 h.p., 1,200 r.p.m. Belted direct to a No. 3 mortising machine.

One 15 h.p., 1,200 r.p.m. Belted direct to one cut-off saw.

One 10 h.p., 900 r.p.m. Belted direct to one 18-in. rip saw.

One 7.5 h.p., 900 r.p.m. Belted direct to one grindstone.

One 5 hp., 1,200 r.p.m. Belted direct to one grindstone.

One 2 h.p., 1,200 r.p.m. Belted direct to one 36-in. band saw.

One 5 h.p., 1,200 r.p.m. Geared direct to one milling machine.

Electric Motors in Harvesting Machine Works. Two articles in Electrical Review and Western Electrician, Oct. 23 and Nov. 13, 1915, describe the application of electric drive to machinery in plants No. 1 and No. 2 of the International Harvester Co. at Auburn, N. Y.; a description of the works is given together with the following account of motors used:

Motor Data — International Harvester Company (Osborne Works). Total connected horsepower, 901.5. Total number of motors installed, 27. Average kw.-hrs. per month per h.p. connected, 125.9.

The following is a list of motors and machinery driven by them.

One 10 h.p., 220 volt, squirrel-cage motor with 1,200 r.p.m. speed and 8 in. pulley, driving two drill presses, one grindstone, one wood lathe, one small wood planer, one small drill.

One 3 h.p., 220 volt, slip-ring motor, 1,200 r.p.m., 6-in. pulley. Blower for brass furnace.

One 50 h.p., 2,080 volt, internal-resistance motor, 900 r.p.m., geared to positive blower 18-oz. higher pressure type supplying three gray-iron cupolas.

One 35 h.p., 2,080 volt, squirrel-cage motor with 900 r.p.m. speed, and 13-in. pulley, driving two tumblers for slag, two freight elevators, one 36-in. fan, one magnetic separator for separating iron from refuse in crushed slag.

One 15 h.p., 220 volt, squirrel-cage motor, 1,200 r.p.m., and 8-in. pulley. One 2-spindle nut-tapping machine, one 12-spindle nut-tapping machine, seven automatic nut-tapping machines, one 8-spindle hand-tapping machine, three Pratt & Whitney automatic screw machines, two National-Acme automatic screw machines, one hand screw machine.

One 50 h.p., 2,080 volt, internal-resistance motor, 900 r.p.m., and 13-in pulley. One annealing furnace, four cold-heading bolt machines, five cold-pressed nut machines, two cold rivet machines, one automatic trip bending machine, one automatic thread roller.

One 50 h.p., 2,080 volt, internal resistance motor, 900 r.p.m., and 13-in. pulley. One cut-off machine, one small cut-off machine, one shears, three punch presses, two power hack saws, one freight elevator, six roll-thread threading machines, six old-style, threading machines, two heavy threading machines, one 6-in lathe, one drill press, one milling machine, one small milling machine, two bolt pointers, six small drill presses, eight 2-wheel emery grinders.

One 40 h.p., 2,080 volt, internal-resistance motor, 900 r.p.m., 13-in. pulley. Eleven large tumblers, four small tumblers, one drill press.

One 25 h.p. direct coupled, 2,080 volt internal resistance motor, 720 r.p.m., driving sixty-inch exhaust fan for removing dust from tumbling room.

One 75 h.p., 2,080 volt internal resistance motor, 720 r.p.m., 18-in. pulley. Three bulldozers, one small bulldozer, one baby bulldozer, one bolt header, one Welderham No. 8 positive blower, one bolt machine, one tire welder, two eye benders, one power hammer.

Two 30 h.p., 2,080 volt internal resistance motor, 900 r.p.m., 12-in. pulley. One 60-in. fan for oil burners; three drop hammers; one power shears.

One 40 h.p., 2,080 volt internal resistance motor, 900 r.p.m., 13-in. pulley. One 14-in. slotter; one 24-in. planer; two vertical milling machines; five grinders; six small twist drills; two 3 spindle drills; one 2 spindle drill; one small 2 spindle drill; six small engine lathes; one freight elevator.

One 10 h.p., 220 volt squirrel-cage motor, 1,200 r.p.m. Two 8-in. engine lathes; one 12-in. engine lathe; one 14-in. engine lathe; three medium size drill presses; one 22-in. surface planer; one band saw; one grind stone; one rip saw; two wood lathes.

One 40 h.p., 2,080 volt internal-resistance motor, 900 r.p.m., 8-in. pulley. Three 8-in. swing engine lathes; seven 10-in. swing engine lathes; one 12-in. swing engine lathe; one 18-in. swing engine lathe; one small horizontal boring mill; one 5½-in. slotter; four 24-in. shapers; one B. & S. 4A milling machine; one small milling machine; three turret lathes; one 5-ft. planer; one 4-ft. planer; two punch presses; one latch rod bender; one cotter machine; two wire straighteners.

One 10 h.p., 220 volt squirrel-cage motor, 1,200 r.p.m., 8-in. pulley. One power hack saw; one 10-in. engine lathe; three small drill presses; one 8-in. engine lathe; one 12-in. shaper; one small forge blower; one tool grinder; three drills.

One 30 h.p., 2,080 volt internal-resistance motor, 9,000 r.p.m., 13-in. pulley. Three freight elevators; one punch press; miscellaneous drills and special rivet machines.

One 75 h.p., 2,080 volt squirrel-cage motor, driving motor-generator set.

One 30 h.p., 2,080 volt internal-resistance motor, 900 r.p.m., 13-in. pulley. Miscellaneous drills.

One 50 h.p., 2,080 volt internal-resistance motor, 900 r.p.m.. 13-in. pulley. Miscellaneous machines including gang drills, turret lathes, key slotters, lathes, emery wheels, punches.

One 30 h.p., 2,080 volt, internal-resistance motor, 900 r.p.m. No.

50 Sturtevant slow-speed exhaust fan for removing shavings and saw dust from box-making department.

One 30 h.p. 2,080 volt internal-resistance motor, 900 r.p.m. Twenty-four in. wood planer in box-making department.

One 40 h.p., 2,080 volt internal-resistance motor, 900 r.p.m., 13-in. pulley. Six cut-off saws; two rip saws; one small wood planer.

One 75 h.p. 2,080 volt internal-resistance motor, 720 r.p.m., 16-in. pulley. Six facing wheels; twelve section grinders.

One 20 h.p., 2,080 volt squirrel-cage motor, 900 r.p.m., 13-in. pulley. Two tempering machines; seven punch presses; one draw-temper fire; one freight elevator; three serrating machines; one multiple drill.

One 0.5 h.p., 220 volt squirrel-cage motor, driving ventilating fan, tempering room.

One 3 h.p., 220 volt squirrel-cage motor on hoist.

One 35 h.p., 220 volt slip-ring motor on elevator.

Motor Data. Manufacture tillage implements. Plant No. 2.

Total connected h.p., 1,079.5. Total number of motors installed, 44. Average kw.-hrs. per month, 143,952. Average kw.-hrs. per month per h.p. connected, 133.3.

The following is a list of the motors installed with their respective drives. The supply source is three-phase, 25 cycles, 2,300 volts and 220 volts, d.-c. The d.-c. motors which are used for cranes, elevators and telphers, are not enumerated herewith. Motors are of the squirrel-cage induction type unless otherwise mentioned.

Two 35 h.p., 2,300 volt, 750 r.p.m. motors. Each driving a No. 13 Sirocco blower for furnaces.

One 10 h.p., 2,300 volt, 1,500 r.p.m. motor with 8-in. pulley. Molding room.— Two wet slag tumblers; one magnetic separator.

One 35 h.p., 2,300 volt, 750 r.p.m. motor with 13-in pulley. Sixteen large tumblers; 6 small tumblers.

One 10 h.p., 220 volt, 1,500 r.p.m. motor with 8-in. pulley. Four emery wheel stands, 2 wheels each.

One 35 h.p., 2,300 volt, 750 r.p.m. motor in hard room.— Exhaust fan for dust collecting.

One 1 h.p., 220 volt motor, in hard room.— Dust collector knocker for agitating screens in dust collector.

One 35 h.p., 2,300 volt, 750 r.p.m. motor with 13-in. pulley. Annealing room.— One broaching press; 1 small bulldozer; 1 punch press; 1 two-wheel emery grinder; 12 36-in. tumblers; 2 tumblers.

One 20 h.p., 2,300 volt, 750 r.p.m. motor with 10-in. pulley. Four drop hammers; two punches.

One 35 h.p., 2,300 volt, 750 r.p.m. motor in annealing room.— Exhaust fan for dust collecting.

One 1 h.p., 220 volt motor in annealing room.— Dust collector knocker for agitating screens in dust collector.

One 5 h.p., 220 volt, 1,500 r.p.m. motor in core room.— Fan for ventilating core ovens.

One 5 h.p., 220 volt, 1,500 r.p.m. motor with 8-in pulley. Core room.— Sand sifter.

One 5 h.p., 220 volt, 1,500 r.p.m. motor with 8-in. pulley. Pattern room.— One drill press; 1 small shaper; 1 emery wheel; 1 wood saw.

One 1 h.p., 220 volt motor in laboratory.— One small engine lathe; 1 paint grinder; 1 small drill press.

One 2 h.p. 220 volt, 1,500 r.p.m. motor in laboratory.— Olson 100,000-lb. testing machine.

One 0.5 h.p., 220 volt motor in laboratory.— Ventilating fan for chemical cabinet.

One 20 h.p., 2,300 volt, 750 r.p.m. motor, 10-in. pulley. Two 12-ft. punches; one 10-ft. double punch; 8 small punches.

One 35 h.p., 2,300 volt, 750 r.p.m. motor 10-in pulley. One 6-ft. punch; 2 10-ft. punches; 1 12-ft. punch; 5 small punches; 2 straightening machines; 1 scrap shears; 1 drill press; 2 small shears; 2 medium punches; 1 header.

One 35 h.p., 2,300 volt, 750 r.p.m. motor, 10-in. pulley. Five drop hammers; 1 welding machine; 3 spoke setting machines; 1 testing machine; 2 annealing furnaces; 1 drill press; 1 upright bulldozer; 3 bulldozers; 1 punch; 1 small drop hammer.

One 20 h.p., 2,300 volt, 750 r.p.m. motor, 10-in. pulley. Three trip hammers; 2 eye benders; 3 punch presses; 1 drop hammer; 1 tire welder; 1 upsetting machine.

One 50 h.p., 2,300 volt, 750 r.p.m. Slip-ring motor driving Sirocco blower for furnaces.

One 50 h.p., 2,300 volt, 750 r.p.m. motor, 13-in. pulley. Three punches; 8 small drill presses; 1 riveter; 2 emery wheels; 1 threading machine.

One 75 h.p., 2,300 volt, 750 r.p.m. Slip-ring motor driving 11 stands of 2-wheel emery grinders.

One 20 h.p., 2,300 volt, 750 r.p.m. motor. Driving 48-in. exhaust fan for removing dust from emery grinders.

One 50 h.p. 2,300 volt, 750 r.p.m., 16 in. pulley. Slip-rig motor driving 2 stickers; 1 wood riveting machine; 1 boring machine; 1 drop hammer; 1 band saw; 1 spoke machine; 1 sandpaper machine; 1 saw.

One 35 h.p., 2,300 volt, 750 r.p.m. motor, 13 in. pulley. Two planers; 1 automatic feed rip saw.

One 20 h.p., 2,300 volt, 750 r.p.m. motor, 10-in. pulley. Six cross-cut saws.

One 35 h.p. 2,300 volt, 750 r.p.m. motor, 10-in. pulley. Two cross-cut saws.

Three 35 h.p., 2,300 volt, 750 r.p.m. motors. Three combinations of two 48-in. fans for removing shavings and sawdust.

One 35 h.p., 2,300 volt, 750 r.p.m. motor, 13-in. pulley. Miscellaneous small woodworking machines.

One 15 h.p., 2,300 volt, 750 r.p.m. motor, 13-in. pulley. One multiple-spindle boring machine; 2 single-spindle boring machines; one boring machine.

One 35 h.p., 2,300 volt, 750 r.p.m. motor, special. Pole machine.

One 20 h.p., 2,300 volt, 750 r.p.m. motor, 10-in. pulley. Three wood shapers; 1 special rip saw.

One 20 h.p., 2,300 volt, 750 r.p.m. motor, 10-in pulley. Two roll turners; 2 wood lathes; three cross-cut saws; 2 drill presses; 3 wood lathes.

One 15 h.p., 2,300 volt, 750 r.p.m. motor, 10-in. pulley. One wood boring machine; 1 wood riveter; one tumbler barrel for small castings.

One 15 h.p., 2,300 volt, 750 r.p.m. motor, 10-in. pulley. Four large paint grinders; 2 small paint grinders.

One three h.p., 220 volt motor, driving pipe-threading machine.

One 35 h.p., 2,300 volt, 750 r.p.m. motor, 13-in. pulley. One wood planer; 2 drill presses; 1 rip saw; one cut-off saw; miscellaneous small tools.

One 23 h.p., 2,300 volt, 720 r.p.m. motor, driving thirty-five kilowatt direct-current generator 250 volts for cranes, telphers and elevators.

One 23 h.p., 2,300 volt, 720 r.p.m. motor, driving thirty-five k.w. generator for 22-flaming arcs.

One 30 h.p. 220 volt. Slip-ring motor driving elevator in warehouse.

Rates for energy are based on 3 factors: Flat rate for the connected motor load in h.p., daily peak load, and sunset peak load. The day peak load obtains for the entire year and the daily peaks are averaged monthly for the basis of charges on this account. The working day is from 7 A. M to 6 P. M, with a 50-min. recess at noon. There is also a Saturday half holiday. The daily peak-load charges are added to the flat-rate charges. From September 15 until March 15, inclusive, the sunset peak is figured, and is also added to the flat-rate charges. The sunset peak is the maximum demand during the time between sunset and closing time, which is 6 P. M., as previously stated.

Electric Drive in Cotton Gins (J. H. Moseley in Electrical Review and Western Electrician July 24, 1915).

Motor Requisites. It is rarely the custom to install more than five 80-saw gin stands in one battery. When more capacity is required two or more identical batteries are used. On this account the largest size motor usually used is not over 75 horsepower. Since the characteristics of gin operation require a simple source of power and a source capable of overloads, due to the varying grades of cotton ginned, the squirrel-cage induction motor is readily adapted to this class of service. Due to the loose lint, which collects around the gin plant, a brushless-type motor is essential. Simplicity of construction and operation makes the constant-speed squirrel-cage type motor an ideal unit for a cotton gin, and universal satisfaction has resulted where this type has been used.

In order to avoid transformer losses a primary voltage of 2,200 is used on all motors above 25 h.p. in the Texas territory. For unloading fans, motor-driven hydraulic pumps, and electrical trampers, 220-volt motors are commonly used.

The only difficulty experienced in using induction motors is that

of line regulation. During the first and last of the season the cotton gin runs only intermittently, and consequently it is necessary to start and stop the motor many times during the day. On a small isolated plant a 75-h.p. induction motor will practically destroy all attempts toward good regulation and on plants of small capacity it is advisable to use a wound rotor with a time-limit controlling switch for starting. It is also advisable to use wound-rotor motors on individual installations of 100 h.p. or more, in order to decrease the starting current.

The One-Motor Gin. Undoubtedly the cheapest way of changing from a steam-driven to an electrically-driven gin is to replace the steam prime mover with one motor, a small air compressor being belted to the main line shaft, to furnish air for the tramper and hydraulic pump. No trouble whatever should be experienced with an installation of this character. However, when the bales are coming in slowly it is necessary with this type of installation to operate the entire gin plant, in order to furnish air for pressing out the bale. The large friction loss prevalent in the gin proper during this part of the operation causes a large power consumption and a correspondingly high cost per bale of cotton ginned.

Two-Motor Gin. This installation can be greatly improved from the economical operation standpoint by using a hydraulic pump belt driven by a 7.5-h.p. motor. With this arrangement not only can a lower pressure be used on the air drum with consequently less power consumption, but the main gin motor may be cut off as soon as the bale has been put through the gin stands. The 7.5-h.p. motor can then be started and the bale pressed out with no loss in power. On one gin, where a record was kept, 287 bales were pressed with a motor driven hydraulic pump for $1.08, or an average of less than two-fifths of a cent per bale.

The Logical Arrangement. Still further economy can be effected by eliminating the air compressor entirely and replacing it with an individually motor-driven electrical tramper. In the ordinary four-stand, 80-saw gin the electrical equipment would consist of one 75-h.p., 2,200-volt, 60-cycle, three-phase, constant-speed, squirrel-cage motor driving main gin stands and unloading and conveying fan (motor would operate at 900 or 1,200 r.p.m.); one 7.5 h.p., 220-volt, 60-cycle, three-phase, constant-speed, squirrel-cage motor, belted to hydraulic pump; one three-h.p., 220-volt, 60-cycle, three-phase, constant-speed, squirrel-cage motor, driving by means of silent chain the electrical tramper.

If desired a 50-h.p. motor can be used instead of the 75-h.p. machine, and a separate 25-h.p. motor direct-connected to the fan equipment, thus eliminating some belt and friction loss. However, this is a matter of comparatively small economy and is hardly justified, due to the increased first cost of the motor equipment.

The 3-motor installation is the most economical installation, since it divides the gin plant into the three units, which really operate independently of each other. Maximum operating efficiency and economy are obtained by this method.

The electrical tramper is operated by a 3-h.p. motor. This

motor is connected by silent chain to a cog wheel operating the vertical member of the tramper, and is operated by means of the regular tramper-operating lever shown. Moving the lever in one direction starts the motor, and causes the tramper to move downward. When the tramper has reached a predetermined point, or has passed the press dogs the motor rotation is automatically reversed, and the tramper is caused to rise. This invention, besides doing away with the air compressor, and consequently lowering the power consumption and ginning cost, eliminates the possibility of "wet packed" bales, which frequently occur in steam-driven trampers, due to leaky cylinders.

Cost of Operation. The data given in the accompanying table for a complete year's operation on 32 different gins, some of them having identical equipment, will give an idea of the variation of power consumption due to the personal equation.

TABLE XXV. COST OF GINNING COTTON OF 32 GINS

	Maximum	Minimum	Average
Stands	8	2	6
Saws per stand	80	70	70
Horsepower installed	200	50	100
Months used	5	2	4
Bales ginned	3,343	87	1,540
Average weight	566	500	525
Kw.-hrs. used	83,950	1,850	29,450
Kw.-hrs. per bale	26.3	14	19
Net cost per bale	$1.12	$0.45	$0.65

Cotton Gin Power Requirements. The term load-factor is used in these data in such a sense that a load-factor of 100% represents the use for 24 hrs. every day of power corresponding to the rated capacity of the motors connected. An operating-time load-factor of 100% represents the use of the rated capacity of the motors for the running hrs. per day specified for each installation.

Gin Plant with 6 Stands of 70 Saws Each. Capacity approximately 5 bales of cotton per hr. Daily operation varies from 2 to 18 hrs. Number of months operated, 8. Total connected h.p., 127.5. Total number of motors installed, 4. Average kw.-hrs. per month, 4,612.

Kilowatt-hour consumption for 8 months:

Month	Kilowatt-hours
January	2,700
February	1,800
March	300
April	2,000
September	1,900
October	16,200
November	9,500
December	2,500

Load-factor, 6.6%.

Approximate energy consumption per bale of cotton ginned is 19.2 kw.-hrs.

Following is a list of motors installed with their respective drives. Source of supply is 220 volts, three-phase, 60 cycles with the exception of 75-h.p. motor which is 2,200 volts.

One 75 h.p., 900 r.p.m. motor, belted to main line shaft driving six 70-saw gin stands and one Gardner-Rix 6 by 6 vertical, two-cylinder air compressor. One 25 h.p., 1,800 r.p.m. motor, direct-connected to 40-in. multi-blade fan for unloading and conveying cotton to gin stands. One 7.5 h.p., 900 r.p.m. motor, belted to hydraulic pump. One 20 h.p., 1,800 r.p.m. motor, direct-connected to 35-in. unloading fan in cotton storehouse.

Gin Plant with 4 70-Saw Stands. Capacity approximately 4 bales of cotton per hr. Daily operation varies from 1 to 18 hrs. Four men are employed. Plant operates 7 months per year. Total connected h.p., 100. Total number of motors installed, 2. Average kw.-hrs. per month, 2,963.

Consumption for 12 months:

Month	Kilowatt-hours
January	311
February	2,610
March	400
April to August	0
September	4,400
October	6,980
November	4,350
December	1,690

Load-factor, 5.4%.

Average kw.-hrs. per bale, 14.5.

Following is a list of motors installed with their respective drives; 220-volt, 3-phase, 60-cycle current is used with the exception of the 75-hp. motor which is 2,200 volts.

One 75 h.p., 900 r.p.m. motor, belted to main line shaft driving 4 70-saw gin stands and one Gardner-Rix 6 by 6 vertical, 2-cylinder air compressor. One 25 h.p., 1,800 r.p.m. motor, direct-connected to 40-in. unloading fan in cotton storehouse.

Gin Plant with Six 70-Saw and Five 80-Saw Stands, having a capacity of approximately 10 bales per hr. Daily operation varies from 1 to 18 hrs. Plant operates 6 months per year. Total connected h.p., 192.5. Total number of motors installed, 5. Average kw.-hrs. per month, 4,937.

Kilowatt-hour consumption for 6 months:

Month	Kilowatt-hours
January	580
February	121
September	11,400
October	12,050
November	5,010
December	460

Load-factor, 4.7%.

The approximate energy consumption per bale ginned is 17 kw.-hrs.

Following is a list of motors installed with their respective drives. Current is supplied at 220 volts, 3-phase, 60 cycles.

One 75 h.p., 900 r.p.m., belted to main line shaft driving six 70-saw gin stands and suction fan. One 15 h.p., 1,200 r.p.m., belted to 8 by 6 Gardner vertical air compressor furnishing air for tramper. One 75 h.p., 900 r.p.m., belted to main line shaft driving five 80-saw gin stands and 6 by 6 Gardner vertical air compressor. One 7.5 h.p., 900 r.p.m., belted to hydraulic pump which operates the hydraulic ram on two presses. One 20 h.p., 1,800 r.p.m., direct-connected to 35-in. unloading fan in cotton storehouse.

Gin Plant with Four 70-Saw Stands having a capacity of approximately 4 bales of cotton per hr. Daily operation varies from 1 to 18 hrs. There are 4 men employed. Plant operates 5 months per year. Total connected h.p., 95. Total number of motors installed, 2. Average kw.-hrs. per month, 7,815.

Kilowatt-hour consumption for five months:

Month	Killowatt-hours
January	3,960
February to August	0
September	11,580
October	16,280
November	6,630
December	620

Load-factor, 15%.

Approximate energy consumption per bale of cotton ginned, 18 kw.-hrs.

Following is a list of motors installed with their respective drives. Three-phase, 60-cycle, 2,200-volt current is used on 75-h.p. motor and 220 volts on 20-h.p. motor.

One 75 h.p., 1,200 r.p.m., belted to main line shaft driving four 70-saw gin stands; suction fan and 6 by 8 Gardner vertical two-cylinder air compressor. One 20 h.p., 1,800 r.p.m., direct-connected to 35-in. unloading fan in cotton storehouse.

Gin Plant Having Eight 80-Saw Stands. Capacity approximately 10 bales of cotton per hr. Daily operation varies from 1 to 18 hrs. Plant operates 6 months per year. Total connected h.p., 235. Total number of motors installed, 7. Average kw.-hrs. per month, 11,820.

Kilowatt-hour consumption for 6 months:

Month	Kilowatt-hours
January	0
February	10,100
March	700
April to August	0
September	12,411
October	26,300
November	18,100
December	3,311

Load-factor, 9.2%.

The approximate electrical energy consumption per bale of cotton ginned is 18 kw.-hrs.

Following is a list of motors installed with their respective drives. The source of supply is 2,200-volt, three-phase, 60-cycle current for the two 75-h.p. motors and 220-volt for the balance.

Two 75-h.p., 1,200 r.p.m., each belted to a line shaft driving four 80-saw gin stands and suction fan. Two 15 h.p., 1,200 r.p.m., each belted to an 8 by 6 Gardner vertical two-cylinder compressor furnishing air for trampers and hydraulic pumps. Two 20 h.p., 1,800 r.p.m., each direct-connected to a 35-in. unloading fan in cotton storehouse. One 15 h.p., 900 r.p.m., auxiliary motor for seed conveyor.

Gin Plant Having Four 70-Saw Stands. Capacity of plant is approximately 4 bales of cotton per hr. Daily operation varies from 1 to 18 hrs. Plant operates 6 months per year. Total connected h.p., 107.5. Total number of motors installed, 4. Average kw.-hrs. per month, 3,671.

Kilowatt-hour consumption for 6 months:

Month	Kilowatt-hours
January	2,290
February	600
March to August	0
September	10,320
October	10,300
November	2,150
December	1,340

Load-factor 6.2%.

The approximate electrical energy consumption per bale of cotton ginned is 17.2 kw.-hrs.

Motors are installed as follows, 220-volt, three-phase, 60-cycle current being used except in the case of the 75-h.p. motor, which is 2,200 volts.

One 75 h.p., 900 r.p.m., belted to main line shaft driving four 70-saw gin stands and suction fan. One 15 h.p., 1,200 r.p.m., belted to Chicago Pneumatic 6 by 6 air compressor. One 7.5 h.p., 900 r.p.m., belted to hydraulic press pump. One 10 h.p., 1,800 r.p.m., belted to unloading fan in storehouse.

Electric Drive in Sand and Gravel Plants. Capacity 1,000 cu. yds. daily. A plant of the Hugh Nawn Contracting Company, Sharon Heights, Mass., capacity, 1,000 cu. yds. a day, 6 to 8 men employed, operating the year around, was described in Electrical Review and Western Electrician.

The total h.p. connected, was 248, total number of motors connected, 15; average monthly cost of power, $280.

Motor Installation. Following is a list of the motors installed and their respective drives. Current is supplied at 230/460 volts, 3-phase, 60 cycles:

Horse-power of motor	Application
82	Excavator with 1.25-yd. bucket.
1	Revolves hopper.
5	18-in. belt, 310 ft. long.
15	20-in. belt, 600 ft. long.

Horsepower of motor	Application
15	20-in. belt up incline trestle.
5	Two motors operate two pulsating screens.
5	Belt 150 ft. long to crusher.
55	Crusher.
10	Belt conveying pebbles and crushed stone to rctary screen.
10	Rotary screen.
10	18-in. belt 600 ft. long under storage bins.
5	Belt conveyor from tailings bin to crusher
20	16-in. belt conveyor 300 ft. long, under sand piles.
5	Rotary sand screen.

Capacity 6,000 cu. yds. Daily. Plant of the Boston Sand and Gravel Company, Scituate, Mass., has a capacity of 6,000 cu. yds. a day; 10 men regularly employed; plant operates 12 months of the year.

Total connected h.p., 530; total number of motors connected, 15; average kw.-hrs. consumed per month, 40,000.

Motor Installation. Following is a list of the motors installed and their respective drives. Current is supplied at 550 volts, 3-phase, 60 cycles:

Horsepower of motor	Application
165	An S. Flory Manufacturing company engine, hauling three-yd. bucket.
35	Flory engine handling suspension cables and bucket-dumping cable.
3	Air compressor for setting friction clutches.
75	Double-drum Mead-Morrison engine hauling conveyor cars to screening and crushing plant.
75	Symons Brothers' rotary crushers, screens, bucket elevator, sand conveyor and paddles for removing sand deposit in tank.
75	2,200-gallon-per-minute Goulds rotary pump, forcing sea water on screens.
5	*Two motors operate.* Two 14-inch belt conveyors carrying materials to storage piles.
3	A 24-inch belt conveyor to storage.
35	*Two motors operate* two 30-inch belt conveyors for loading lighters.
5	Fresh water pump.
—	In blacksmith shop. Two motors.

Motor-Service and Heating Costs in a Jewelry Factory. The jewelry factory of the Codding-Heilborn Company, North Attleboro, Mass., operated by central-station energy from the local electric plant, was described in Electrical World, June 21, 1913.

The factory was formerly operated by a 50-h.p. slide-valve engine supplied with steam from a 90-h.p. horizontal return-tubular boiler. No traps were used in the steam piping which supplied various parts of the factory with heat. Considerable annoyance was experienced from time to time at the slowing down of the rolling mill, polishing apparatus and steam-driven blower equipment, production being sensibly diminished under mechanical driving. The introduction of electric motors, however, speeded up the polish-

ing tools enough to give about 13% greater production, besides resulting in a better quality of work. All motors are of the 220-volt, three-phase, 60-cycle induction type.

MOTOR EQUIPMENT FOR JEWELRY FACTORY

First floor, 1,200 r.p.m. motors:

Scratch-brushing and coloring, including two direct-current plating dynamos, three scratch-brushing heads and one 13-in. exhaust fan, 3 h.p.
Polishing bench, No. 4 blower, six heads, 7.5 h.p.
Duplex power pump in engine room, 2 h.p.
Three rolling mills, 7.5 h.p.
Two high-speed drills, three lathes, 0.5 h.p.
Tub-cleaning machine, 0.25 h.p.
Emery wheel, double 10-in. diameter, 1 h.p.
Two drop hammers, 450-lb. and 300-lb.; two 200-lb. and two 75-lb. drop hammers, one power press and one rotary shear, 5 h.p.

Second floor, 1,800 r.p.m. motors:

Machine shop, including two engine lathes, one shaper, one emery wheel, one cut-off saw, one grindstone, one milling machine, 2 h.p.
Four power presses, six high-speed lathes, 2 h.p.

Third floor, 1,800 r.p.m. motor:

No. 3 American gas-furnace blower, 2 h.p.

The total connected load of motors is 32.75 h.p., representing an investment of $668.

In this, as in many other cases where isolated plants are to be converted, the question of heating was an important factor.

Cost of Electricity. The estimated cost of electric energy for this factory was $66 per month, based upon a 10-hr. day and service used 300 days per year. The average monthly consumption of energy determined was 2,200 kw.-hrs., the average rate being 3 cents per kw.-hr. The point was made that central-station service would be available at all times, and that a licensed engineer or fireman would not be needed so long as the steam pressure was kept below 15 lbs. per sq. in., since steam was not to be used for developing mechanical power. It was necessary, however, to equip the boiler with a sealed safety valve set at 15 lbs. per sq. in. and approved by the State inspector of boilers.

The total cost of equipping the factory for electric driving was estimated as follows: Motors, complete, with bases, pulleys, labor, freight, $668; wiring, fittings, switches and erection, $160; pulleys, belting, shafting hangers, erected, $80; drying boxes connected to vats, piping and labor, $12; total, $920.

The estimated yearly cost of operation, excluding fixed charges, was $1,444.50, the items being as follows: Electrical energy, $792; coal for heating, 59 tons at $4.50, $265.50; coal for commercial uses, sinks, etc., $207; attendance, one-quarter of the time of one man at $60 per month, inspecting motors, firing boiler, etc., $180; total $1,444.50.

CHAPTER XV

COMPRESSED AIR

Compressors are sold on a basis of displacement in cu. ft. of free air per minute. This in the case of double-acting compressors is the volume of the air cylinder in cu. ft. multiplied by twice the number of revolutions per minute, or the volume of the air cylinder in cu. ft. multiplied by the piston speed in ft. per min. In the case of 2- or 3-stage compressors the displacement is naturally figured on the basis of the volume of the low pressure cylinder.

Thus, a 6 by 6 in. single stage machine at 150 r.p.m. would have a displacement of

$$\frac{1}{2} \times \frac{\pi \times 3^2}{144} \times 2 \times 150 = 29.4 \text{ cu. ft. per min.}$$

An 8 by 10 in. single stage machine at 200 r.p.m. would have a displacement of:

$$\frac{10}{12} \times \frac{\pi \times 4^2}{144} \times 2 \times 200 = 116.4 \text{ cu. ft. per min.}$$

A 30 by 18 in. by 24 in. 2-stage machine at 150 r.p.m. would have a displacement of:

$$\frac{24}{12} \times \frac{\pi \times 15^2}{144} \times 2 \times 150 = 2945.2 \text{ cu. ft. per min.}$$

In the latter case the piston speed was 600 ft. per min., which, multiplied by the volume of the cylinder, 4.9087 cu. ft., gives the displacement 2945.2 as shown.

TABLE I. STEAM DRIVEN TANDEM STRAIGHT LINE COMPRESSORS — SIMPLE STEAM, 2-STAGE AIR — 100 LB. PRESSURE

Rated capacity cu. ft. per min.	Approx. weight, lbs.	Price
400	9,900	$1,235
600	16,000	1,810
800	22,200	2,580
1,000	28,000	2,800
1,250	34,500	3,310
1,500	40,000	3,680
1,750	45,000	3,960
2,000	48,500	4,170
2,250	52,000	4,370
2,500	54,000	4,480

TABLE II. STEAM DRIVEN SIMPLE STRAIGHT LINE COMPRESSORS

100–125 LBS. AIR PRESSURE

Rated capacity cu. ft. free air per min.	Approximate shipping weight in lbs.	Price f.o.b. factory
60	2,600	$ 400
100	3,800	560
150	5,150	720
200	6,500	865
250	7,700	1,000
300	9,000	1,125
400	11,200	1,225
500	13,100	1,580
600	15,500	1,770

80–100 LBS. AIR PRESSURE

Rated capacity cu. ft. free air per min.	Approximate shipping weight in lbs.	Price f.o.b. factory
100	2,950	$ 450
150	4,100	595
200	5,200	730
250	6,200	830
300	7,200	945
400	9,000	1,135
500	10,800	1,320
600	12,500	1,490

TABLE III. CROSS-COMPOUND STEAM-DRIVEN TWO-STAGE AIR COMPRESSORS

(For 125–150 lbs. air pressure)

Rated capacity in cu. ft. per min.	Approximate shipping weight in lbs.	Price f.o.b. factory
200	13,000	$1,760
300	14,500	1,960
400	16,500	2,150
600	24,500	3,130
800	34,000	4,250
1,000	41,000	5,000
1,200	46,000	5,500
1,400	50,000	6,000
1,600	52,000	6,250

TABLE IV. CROSS-COMPOUND STEAM DRIVEN 2-STAGE COMPRESSORS

(For 80–100 lbs. air pressure)

Rated capacity in cu. ft. per min.	Approximate shipping weight in lbs.	Price f.o.b. factory
200	8,600	$1,160
300	9,250	1,250
400	11,000	1,500
600	17,500	2,300
800	24,000	3,060
1,000	29,000	3,600
1,200	34,000	4,250
1,400	37,500	4,700
1,600	40,000	5,000

TABLE V. DUPLEX SIMPLE STEAM DRIVEN TWO-STAGE AIR COMPRESSOR

(For 125–150 lbs. air pressure)

Rated capacity in cu. ft. per min.	Approximate shipping weight, lbs.	Price f.o.b. factory
200	12,000	$1,620
300	13.000	1,760
400	14.500	1,920
600	26,000	3.320
800	33,000	4,130
1,000	36,000	4,150
1,200	37,000	4,250

TABLE VI. DUPLEX SIMPLE STEAM DRIVEN SINGLE-STAGE AIR COMPRESSORS

(For 45–60 lbs. air pressure)

Rated capacity in cu. ft. per min.	Approximate shipping weight, lbs.	Price f.o.b. factory
200	6.000	$ 760
300	6.600	840
400	7.600	970
600	11,000	1,380
800	15.000	1.800
1,000	19.500	2.340
1,200	23,500	2,760
1,400	27,500	3,160
1,600	31,000	3,560

TABLE VII. DUPLEX SIMPLE STEAM DRIVEN SINGLE-STAGE AIR COMPRESSORS

(For 100 lbs. air pressure)

Rated capacity in cu. ft. per min.	Approximate shipping weight, lbs.	Price f.o.b. factory
200	7,500	$ 950
300	10,000	1.250
400	12.500	1.560
600	18,500	2,220
800	23,500	2.760
1,000	28,000	3,220
1,200	31,000	3,560
1,400	34,000	3,900
1,600	36,000	4,050

TABLE VIII. DUPLEX CORLISS COMPOUND STEAM DRIVEN TWO-STAGE AIR COMPRESSOR WITH TANDEM CYLINDERS

(For 90–100 lbs. air pressure)

Rated capacity in cu. ft. per min.	Approximate shipping weight, lbs.	Price f.o.b. factory
2,000	9,600	$1,200
2,500	10,500	1,310
3,000	11,500	1,440
3,500	13,000	1,630
4,000	14,500	1,780
4,500	16,000	1,920
5,000	17,000	2,040
5,500	18,500	2,220

TABLE IX. DUPLEX SIMPLE STEAM DRIVEN TWO-STAGE AIR COMPRESSOR

(For 80–110 lbs. air pressure)

Rated capacity in cu. ft. per min.	Approximate shipping weight, lbs.	Price f.o.b. factory
200	8,000	$1,000
300	8,600	1,075
400	10,000	1,250
600	16,000	1,920
800	21,000	2,520
1,000	26,000	3,060
1,200	30,000	3,450
1,400	33,000	3,800
1,600	36,000	4,050

Formulae of Costs of Air Compressors. A. A. Potter in Power, Dec. 30, 1913, derived the formulae in Table X for the costs of air compressors, by tabulating and plotting the net prices received from several different manufacturers. The prices are the net selling price f.o.b. factory and do not include cost of erection.

TABLE X. COST FORMULÆ FOR AIR COMPRESSORS

Type	Capacity up to cu. ft. per min.	Equation of cost in dollars
Single cylinder, belt driven....	4,000	52 + 1.95 × cu. ft.
Duplex, belt-driven	850	316 + 1.675 × cu. ft.
Compound, belt-driven	550	3.1 × cu. ft.
Single cylinder, steam driven..	350	231 + 2.32 × cu. ft.
Duplex, steam-driven	600	460 + 2.55 × cu. ft.
Compound, steam-driven	500	71.25 + 4.025 × cu. ft.

TABLE XA. COST OF MOTOR DRIVEN COMPRESSORS WITH AUXILIARIES AND THEIR INSTALLATION

	220 V	220 V	220 V	600 V	600 V	600 V
Piston displacement, cu. ft. per min.	15	25	50	50	15	25
Shipping weight	630	830	2050	1460	620	880
Net price compressor, f.o.b. factory	$220.	260.	450.	400.	175.	225.
Net price governors and switch, f.o.b. factory.	40.	40.	40.	20.	20.	20.
Freight and drayage at $1.50	9.	12.	31.	22.	9.	13.
Est. cost of receiver, piping, etc.	40.	40.	40.	40.	40.	40.
Installing	15.	15.	15.	15.	15.	15.
	$324.	367.	576.	497.	259.	313.

Cost of Installing a Compressor Plant. The following, taken from Gillette's Handbook of Rock Excavation, is an itemized account of the cost of installing a small compressor plant. The compressor was a Rand, Class C, 24 by 30-in., that cost $1,000. The boiler was a second-hand 150 hp. locomotive boiler that cost $1,000. This plant was capable of furnishing 1,300 cu. ft. of free air per min. at

80 lbs. pressure, or enough to run 10 or 12 drills. Cost of installing boiler:

22 days laborers, at $1.50	$ 33
23 days engineers, at $3	69
13 days mechanics, at $4	52
13 days mechanics' help, at $2	26
1 day bricklayer, at $4	4
Total	$184

Cost of installing compressor:

120 days laborers, at $1.50	$180
4 days engineers, at $3	12
22 days mechanics, at $4	88
80 days mechanics' help, at $2	160
50 days carpenters, at $3	150
3 days bricklayers, at $4	12
6 days teams, at $4	24
8 days foremen, at $3	24
Total	$650

Cost of materials:

15M lumber for housing compressor, at $25	$375
1,400 sq. ft. tar paper (1 layer)	21
32 cu. yd. concrete, at $4	128
5M brick, at $7	35
6 bbl. cement, at $2	12
Sand	1
Total	$572

Cost, Air Capacity, etc., of Different Types of Portable Compressors. From a table in Dana's Handbook of Construction Plant we have compiled the following. A compressor delivering 78 cu. ft. free air per min. at a pressure of 100 lbs., having single stage water jacket, Ingersoll-Rand type 8 x 8, NE-I, and 4 water cooling tanks with rotary circulating pump, driven by a 15 hp., 1 cyl., gasoline engine, weighs, complete, 7,700 lbs. and costs $1,425. A compressor delivering 64 cu. ft. free air with a Franklin single stage water jacket, but like the above in all other respects, weighs, complete, 7,800 lbs. and costs $1,325. A compressor delivering 70 ft. air at 90 lbs., having the gas and air cylinder cast in one piece, worked tandem with single piston rod, weighs over 7,000 lbs. and costs $1,250. A compressor delivering 70 cu. ft. air at 80 lbs., with a 12 hp. single cyl. engine, weighs, complete, 8,900 lbs. and costs $1,120. One delivering 94 ft. of air at 90 lbs., with 20 hp. engine, weighs 9,000 lbs. and costs $1,825. One delivering 100 ft. air at 90 lbs., driven by a 4-cyl. marine type gasoline engine of 27 hp., water circulating with radiator, weighs 8,000 lbs. and costs $1,900.

Air Receivers. The information in Table XI in regard to air receivers, sizes, weights, etc., has been obtained from several of the large manufacturers of compressed air machinery.

Turbo-Compressors. The modern turbo-compressor is suitable for pressures up to 120 lbs. per sq. in. They may be driven by direct connected steam turbines or by electric motors.

TABLE XI. COST OF AIR RECEIVERS

Compressor capacity for which best adapted, cu. ft. free air per min.	Contents of receiver, cu. ft.	Weight of receiver, lbs.	Price
100– 250	30	700– 825	$ 45
150– 325	43	1,000–1,050	55
200– 450	57	1,200–1,300	70
300– 650	77	1,550–1,600	85
500– 900	96	1,750–1,900	100
800–1,500	150	2,400–2,900	145
1,200–2,000	192	3,200–3,400	180
2,000–3,500	280	3,900–5,200	250
3,500–4,000	380	6,300	315

The following are some of the advantages of turbo-compressors:

1. The turbo-blowers and compressors deliver a steady (non-pulsating) current of air or gas.
2. Run practically without noise at all loads.
3. Simple in construction, have all parts easily accessible, and are reliable in action.
4. Not only require very little attendance and lubrication when at work, but relatively speaking, a minimum of space for their accommodation.
5. Require a minimum of power to drive; they are also easily governed through a wide range of variation of speed, without materially affecting their economy.
6. Perfectly balanced both dynamically and in respect of axial thrust.

Turbo-Auxiliary to Piston Compressor in an English Mine. A case arose at an English colliery, where, in order to meet the increased demand for air, either the existing piston-compressor plant — a cross-compound engine with cylinders 28-in. and 50-in. diameter, by 60-in. stroke, driving duplex air cylinders of 33-in. diameter, running up to from 30 to 35 r.p.m. as a maximum — could be augmented by a similar set, or, with a view of increased efficiency on the air cylinders, by the installation of a compound two-stage compressor, or finally by the adoption of a turbo-compressor set receiving its driving energy from the exhaust (at about atmospheric pressure) of the low pressure steam cylinder. Here the plan contemplated was that the turbo-compressor should pass its discharge through an inter-cooler into the existing air cylinders.

It was found that the costs of the second complete piston compressor would very much exceed the first cost of the turbo-compressor installation, and it would also require much more floor space; moreover, a gain of efficiency could be obtained only with the new piston compressor plant, whereas the turbo-compressor would improve the working efficiency over the whole combined capacity. For these reasons, therefore, it was decided to install the turbo-compressor. The results have fully justified this decision, a gain of about 17% over what would have been secured from a second piston compressor having been obtained.

The turbo-compressor is of the Rateau type, and was subjected to tests which proved that the guarantees were fully realized,

easily delivering from 6,000 to 7,000 cu. ft. of free air per min. at 12.8 lbs. gage. The steam consumption claimed for the turbine also was established. The flexibility of the plant was particularly noteworthy, as outputs up to 12,000 cu. ft. per min. and pressures up to 16 lbs. were easily realized.

When running the existing piston compressor at the normal speed of 30 r.p.m. taking in air at atmospheric pressure and temperature, the maximum volume discharged at 60 lbs. was 3,000 cu. ft. of free air per min., while with the addition of the turbo-compressor set, with the piston compressor at the same speed as before, an increase in the free air capacity of over 100% was obtained, and the total efficiency both of the air and of the steam was greatly improved.

The low pressure steam cylinder of the existing duplex piston compressor now discharges into a large steam receiver — an old boiler shell with automatic relief valve arranged to prevent undue accumulation of pressure. From this the steam passes through the exhaust steam turbine to the condenser arranged underneath the turbine exhaust branch. The turbine is absolutely under the control of the reciprocating compressor, as a demand for more work from the plant requires more steam from the duplex compressor, and provides the turbine with the necessary steam for the required air capacity or pressure.

Economy in Compressed Air Mining Plants. No subject connected with the operation of a mine has more interest to the miner than that of cheap power.

E. A. Rix in the Proceedings of the California Miners' Association (1903) states that another and more important feature which is too frequently overlooked, is the amount of power which is used in mining operations. It is just as economical and important to effect a reduction of 25% in the amount of power used as to effect the same reduction in the rate. The power required to operate the compressed air plant about a mine is a considerable item, being from 25 to 50% of the total power used, and it is safe to say that of this, from 25 to 50% could be saved in very many plants with but comparatively small expenditure.

With any given compressor, there is a saving to be made of from 5 to 10% in favor of driving direct by a water wheel or steam engine, rather than by means of gear or belt. But this is not always practical or feasible. A great saving may be made in the ordinary steam-driven compressor as far as the motor end is concerned. The engines of steam-driven compressors are ordinarily equipped with either plain slide valves, Meyers cut-off gearing, or compound cylinders.

The plain slide valve engine consumes from 45 to 50 lbs. of steam per h.p.-hr. The steam consumption is large because the mean effective pressure required to do the work being low, the steam is throttled at the governor, or shut-off valve, and introduced into the steam cylinder at low pressure, thus giving no benefit from the high steam pressure or expansion.

The Meyers cut-off, however, does away with much of this loss

and gives the steam a chance to work expansively, and the steam consumption will probably be from 35 to 40 lbs. per h.p.-hr.

With the compound engine, the steam consumption will be from 30 to 35 lbs. per h.p.-hr. Condensing engines would give larger economy, but for the average mining plants would not be desirable.

Taking these figures, it will be noted that the Meyers cut-off is at least 20% more economical than the plain slide valve, and the compound cylinders are 30% more economical. For example, a three-drill compressor — 12 by 12 by 12 ins. cost

	Cost
Plain slide valve	$1,300
Meyers cut-off	1,350
Compound cylinder compressor	1,650

This is a 50 h.p. compressor, and if a h.p. should cost but $5 monthly, the Meyers cut-off would pay for its extra cost in a month and the compound in five months, after which there would be a clean saving of $50 to $75 monthly, an item not to be overlooked.

It has been quite well demonstrated that a two-stage compressor for pressures above 60 or 70 lbs. is very much more desirable and economical than a single stage machine.

(1) It requires from 10 to 15% less power to compress 90 or 100 lbs. by a two-stage machine.

(2) The temperature created by compression is only about one-half, that is to say, from 200 to 250 degs. F. in the cylinder, instead of from 350 to 450 degs. The lower temperature permits better lubrication and wear in the cylinder and does away with the danger of cylinder or receiver explosions due to the ignition of the gases given off by the lubricants.

In the third place: It gives a proper capacity of air delivered for the size of the air cylinder. Right here is a point which should appeal to every one.

All compressor catalogs give the rated capacity of a compressor in cu. ft. of piston displacement, at a certain speed, and too frequently purchasers believe that these figures indicate the free air capacity. If they buy a machine having one hundred cu. ft. displacement at 150 r.p.m., the supposition is that the compressor will deliver about that quantity. This may be nearly true of a two-stage compressor, but not of a single-stage machine. The single-stage machine is generally equipped with poppet valves, and the considerations of speed, valve clearance, piston clearance, piston leakage, valve leakage, temperatures, valve inertia, springs, tensions and atmospheric temperature, all tend to reduce this displacement figure, until the average poppet valve single-stage machine does not give over 75% of its theoretical volume at normal speed, and may drop to from 50 to 60%. This means that while the machine is built for and is amply strong enough to give 100% it is not permitted to deliver its full volume by reason of the facts set forth. The purchaser finds he cannot get air enough for his work.

The two-stage machine will give from 85 to 90% of its theoretical displacement, and with this machine the purchaser is therefore

getting more for his money, buying the same cylinder dimensions, than in the single-stage machine.

A single-stage straight line machine, 12 and 12 by 12 ins., will cost $800. A two-stage, 12 and 7 and 12 by 12 ins., will cost $980. Inasmuch as the two-stage machine will give 15% more air, the comparative price of the single-stage machine would be figured at $920. Consequently, the difference in price is $60, and because the 2-stage machine is more economical to operate by 15%, this small difference in price will be saved in two or three months.

To conclude, then, as far as the compressor end is concerned, there are the following gains to be made, counting that the compressor is running at capacity ratings as to speed and pressure:

In power required, for a 2-stage compound steam-driven machine over a single-stage plain slide valve, a gain of at least 50%.

In volume, a gain of 15 to 25%.

In cost, an insignificant increase compared to the saving.

In power actuated compressors, the corresponding gain would be a saving of about 15% in power and a gain in volume of from 15 to 25%. A 12 by 12 ins., belt-driven, single-stage compressor will cost $660, and a two-stage 12 and 7 by 12 ins. will cost $860. Allowing for the difference in volume delivered, the comparison will be as $760 is to $860, a difference of $100, which will be saved in power in 3 months.

For altitudes, the gain in using a 2-stage compressor is still more marked.

The next loss is in the pipe lines, where insufficient sizes cause a frictional loss of pressure and leaks cause a loss of volume. The latter is generally the greater. Tests of a great many pipe lines in mines develop the fact that probably none are tight and the majority leak from 10 to 30%. Small leaks at each joint, which can only be discovered by using soap and water, make a considerable total loss.

For example, upon installing a large compressor under guarantee, at a well-known mine, a test was made for leakage. The pipe lines were long and numerous, having accumulated during 10 years' working, and the mine manager was willing to allow but 5% loss for leakage. The pipes were sealed at all terminals and valves, and the compressor speed regulated so that it would hold the pipe line at exactly 90 lbs. It required 40% of the maximum revolutions of the compressor to hold the pressure. It was a surprise to every one. After a week's work on the lines the loss was reduced to about 12% and there remained. It is doubtful if the average pipe lines lose less than 15%.

It is a simple matter to determine and easy to remedy while installing the pipe. The loss should not be allowed to exceed 5% if economy is desired, and a line may with care be made practically tight. It seems a simple job to screw pipe together so it will not leak, yet it is not so, for it requires patience and experience. Plumbers encounter great difficulties in piping large buildings, yet their work must not leak, and the same degree of attention will

give the same result for a mine and it will pay well to have it done properly from the very start.

The next source of loss is in using pipes that are too small. The temptation to use small pipes in levels and stopes is great because they can be put in place so readily. But they occasion great loss; in many instances, pressure gauges placed on the drill hose have given readings of from 45 to 60 lbs., with from 80 to 90 lbs. at the compressor.

It must be remembered that a drop of pressure of 10 lbs., from 90 to 80, for example, does not mean a 10% power loss — the loss is but 4%, but the loss in the work performed by the drill more than makes up for it. It would probably not be amiss to state here that the average pipe lines could be bettered at least 10% by stopping and using proper size of pipes.

It seems to be quite well understood at present that hoisting engines operated by compressed air should have the air reheated before use, and many have introduced either dry air heaters or steam heaters for their hoists.

In a hoisting engine, it takes about 25 cu. ft. of free air compressed to 90 lbs. to give a h.p. used cold, and about 16 cu. ft., or a saving of 35%, when properly heated.

If compound engines be used on the hoist, and the air be heated to about 400 degs. F. before using in each cylinder, a h.p. can be produced readily with 8 cu. ft. of free air per h.p. or two-thirds less than in an ordinary hoisting engine.

Where a good-sized hoist is used, the loss in using primitive methods runs into money very fast. As an example of how insignificant things cause losses in compressed air machines, my attention was called recently to a mill engine, driven by compressed air, that failed to give the stamps the requisite drops because the air supply was insufficient, although the air was reheated. Upon examining the engine, it was found to have an unusual clearance, and a three-eighths plate fastened on each face of the piston reduced the loss so that it performed the work in a most satisfactory manner. There are many engines running with similar losses in the mines to-day.

Compressed air hoists on the surface, and particularly under ground, should have sufficient receiver capacity attached, so that when the hoists are working they do not reduce the pipe line pressure too much, otherwise the work of the rock drills will fall off materially, but the machine men's wages are going on just the same.

The greatest loss in connection with the use of compressed air in mines is in using the ordinary direct acting pump for station work, and but little progress has been made toward bettering this condition in any but two or three larger mines. The facts are these:

At 90 lbs. air pressure, if it takes 100 cu. ft. of free air to do a certain amount of pumping, using an ordinary direct acting pump, then 75 cu. ft. will do the same work if the air be heated to 300

degs. Sixty cu. ft. will be required in a compound direct acting pump where the heating is only enough to keep the pump from freezing. Fifty cu. ft. will be required if heating be done to 300 degs. before using in the high-pressure cylinder. Forty cu. ft. only will be required if heating be done to 300 degs. before using in the low-pressure cylinder also. Thirty-five cu. ft. will be required for the work in a triple-cylinder pump.

In other words, it is possible to save two-thirds of the air. It is not much trouble to do this heating underground, and the saving is enormous. Distillate at 5 cts. per gal. can be used for heating. It is not dangerous, the odor amounting to nothing in a well-ventilated mine. Where any quantity of water is to be pumped, a small flue pipe can be run in one corner of a shaft compartment. This economical style of pumping is in constant and satisfactory use at the North Star Mines on their lowest levels.

Compressed air may be used in pumping in such a manner that its commercial economy may more than offset its mechanical economy. Commercial economy has for its basis the total cost to accomplish an end rather than the cost at any unit of time. For example, the Brunswick Mine at Grass Valley struck a flow of water on the 1,250-ft. level that the Cornish pump could not handle, and the mine filled to the 700-ft. level, at which point the Cornish pump held the water. The problem was to recover the 1,250-ft. level and establish a station pump there. It is evident that if there was no water flowing into the mine, the most economical way to remove it would be to apply pumps that were mechanically economical and the situation would be very simple. The shaft is so small that large pumps and their pipes and appurtenances were difficult to handle, and at every 25 ft. they would have to be stopped, disconnected, lowered and connected up again, which would have caused a great deal of delay, during which time large volumes of water are coming into the mine. Consequently, the situation came to be one where the system that would get the water out quickest and thus gain on the incoming water would probably cost least by the time the water was out, although perhaps costing more per foot-gallon pumped.

With this idea in view; an air lift was installed at the 700-ft. level of the Brunswick, to deliver water to the Cornish and also to an electric pump established on that station. An 8-in. water main was lowered on trucks down the shaft, as far as possible, to give submergence, and then a 2½-in. air pipe was lowered into this, and followed down at proper distances relative to the lowering water in the shaft. The quantity delivered was about 800 gals. per min. at the beginning and sixteen days from starting, the 1,000-ft. level was uncovered, and 250 gals. per min. were being delivered with a vertical lift of 300 ft. and a submergence of only 230 ft. On account of the rapidity with which the water was lowered, this method was commercially very economical, and this simple and inexpensive arrangement is commended to others.

To secure the actual h.p. required to compress a given volume of air to any desired pressure, 10 to 15% should be added to the figures

TABLE XII. HORSEPOWER (THEORETICAL) REQUIRED TO COMPRESS 100 CU. FT. FREE AIR TO VARIOUS PRESSURES

Gauge pressure	Single-stage	Two-stage	Saving of two-stage over single-stage compression Horsepower	Per cent.
5	1.97	....	....	....
10	3.61	....	....	....
15	5.02	....	....	....
20	6.28	....	....	....
25	7.44	....	....	....
30	8.45	....	....	....
35	9.41	....	....	....
40	10.30	....	....	....
45	11.13	....	....	....
50	11.92	10.65	1.28	10.70
55	12.67	11.25	1.42	11.22
60	13.37	11.81	1.57	11.72
65	14.05	12.34	1.71	12.18
70	14.70	12.84	1.85	12.61
75	15.32	13.32	2.00	13.04
80	15.91	13.77	2.13	13.40
85	16.48	14.21	2.27	13.77
90	17.04	14.63	2.41	14.12
95	17.57	15.03	2.54	14.45
100	18.09	15.42	2.67	14.77
110	19.08	16.15	2.93	15.36
120	20.01	16.83	3.18	15.90
130	20.90	17.46	3.43	16.42
140	21.74	18.07	3.67	16.89
150	22.55	18.64	3.91	17.33
160	23.32	19.26	4.06	17.40
170	24.06	19.78	4.29	17.80
180	24.77	20.27	4.51	18.18
190	25.46	20.74	4.70	18.46
200	26.12	21.19	4.93	18.88
210	....	21.54	....	....
220	....	21.96	....	....
230	....	22.37	....	....
240	....	22.76	....	....
250	....	23.03	....	....
260	....	23.28	....	....
270	....	23.84	....	....
280	....	24.19	....	....
290	....	24.53	....	....
300	....	24.85	....	....
350	....	26.35	....	....
400	....	27.65	....	....
450	....	28.85	....	....
500	....	29.97	....	....

shown above, depending upon the size and type of the compressor, to allow for mechanical losses.

Conversion of Free Air to Compressed Air. Table XIII from Mine and Quarry, April, 1913, gives the equivalents of free air to compressed air.

Example: Given 348 cu. ft. of air compressed to 95 lbs. pressure at 4,000 ft. altitude. Opposite 4,000 and below 95 appears the figure 8.53. $8.53 \times 348 = 2{,}968.44$ = volume in "free air."

Air Compressor Economy in New York City. Tests were made by Smith, Hauser, Locher and Co. on two compressors of different makes, used to supply air for rock tunnel work on the Catskill Aqueduct from 99th St. to 14th St. in New York City. From a de-

TABLE XIII. CONVERSION COMPRESSED AIR TO FREE AIR

Altitude, ft.	Barometer	Atmospheric pressure	Gauge pressure, lbs. 50	60	70	80	90	100	110
0	30.00	14.7	4.40	5.08	5.76	6.44	7.12	7.80	8.48
500	29.45	14.45	4.46	5.15	5.83	6.53	7.23	7.92	8.61
1,000	28.90	14.12	4.54	5.24	5.95	6.66	7.37	8.08	8.79
1,500	28.35	13.92	4.59	5.31	6.03	6.75	7.46	8.18	8.90
2,000	27.78	13.61	4.67	5.41	6.14	6.88	7.61	8.34	9.08
3,000	26.75	13.10	4.81	5.58	6.34	7.10	7.87	8.63	9.40
4,000	25.75	12.61	4.96	5.76	6.55	7.34	8.14	8.93	9.72
5,000	24.78	12.15	5.11	5.94	6.76	7.58	8.40	9.22	10.05
6,000	23.86	11.75	5.24	6.16	6.96	7.81	8.66	9.51	10.36
7,000	22.97	11.27	5.43	6.32	7.21	8.10	8.98	9.87	10.76
8,000	22.10	10.85	5.61	6.53	7.45	8.37	9.29	10.21	11.14
9,000	21.30	10.45	5.78	6.74	7.70	8.67	9.61	10.57	11.52
10,000	20.60	10.10	5.95	6.94	7.93	8.92	9.91	10.90	11.88

tailed account of these tests, given by F. A. Halleck in Mine and Quarry, March, 1912, we have abstracted the following:

Motor-Driven Air Compressors. Compressed air for the 3 uptown shafts is supplied by a central plant in Central Park, consisting of three Sullivan "Class WN-2" direct connected, two stage air compressors, each driven by a self-starting synchronous motor, mounted on the crank shaft and rated at 400 h.p. at 188 r.p.m. The voltage is 6,600 in the stationary armature and the revolving field is excited by a direct current generator running at 675 r.p.m., and delivering current at 125 volts. This generator is driven by a belt from the crank shaft of the compressor. The compressors have high pressure cylinders 15½ ins. in diameter, low pressure cylinders 26 ins. in diameter, and a common stroke of 18 ins. This gives a piston displacement per unit, at 188 r.p.m., of 2,070 cu. ft. per min.

There are two Corliss inlet valves on each cylinder, moved by eccentrics on the crank shaft. The air is discharged through cushioned poppet valves of a special pattern. The port area of the discharge valves is 16% of the cylinder area in the low pressure cylinder, and 17% in the high pressure cylinder.

The intercooler in these machines is vertical and placed between the air cylinders. The intercooler provides 10.75 sq. ft. of cooling area per 100 cu. ft. of free air. Copper water tubes are used.

The volume of air delivered is proportioned to the demand by means of a double beat unloading valve on the air inlet of the intake cylinder. This valve is either fully open or tightly closed, so that no choking effect is exerted on the entering air; and is operated by a variation of five lbs. in the receiver pressure.

A fly-wheel weighing 7,000 lbs. renders the action of the machine smooth and even in picking up its load, as well as at all other times, and eliminates peaks in the power consumption. The machine and fly-wheel without the motor weigh 22 tons.

At each of the three downtown shafts air is supplied by a single compressor of the two-stage, duplex pattern, of another make, direct-driven by a self-starting synchronous motor, using 6,600-volt current. The dimensions of these machines are: cylinder diam-

eters, low pressure, 25¼ ins.; high pressure, 15¼ ins.; stroke, 21 ins. The piston displacement of each unit is 2,119 cu. ft. per min. at 188 r.p.m. Air enters the cylinder through piston inlet valves, and is discharged through poppet valves.

The amount of air delivered is proportioned to the demand by a clearance controller, designed to operate for no load, ¼, ½ and ¾ loads. In this system of unloading, reservoirs are provided, into which a portion of the air compressed at each stroke is diverted, depending on the quantity of air required for use. This air flows back into the cylinder on the return stroke of the piston, decreasing, by the amount of its volume, the intake capacity of the compressor.

Test of Compressors. The contractors decided to test one machine of each type, in order to learn as closely as possible the actual air delivery and power consumption, or in other words, the relative electrical input per cu. ft. of air actually delivered. On January 18, 1912, unit No. 3 of the plant in Central Park was tested, and on January 22, the piston inlet machine at 50th St. was tested, under identical conditions.

At the time these tests were made, both compressors had been at work under actual service conditions for a number of weeks. No special preparations or adjustments for the test were made on either machine. The makers of each compressor were given abundant notice of the time and purposes of the test, and both had engineers on the ground, who checked the readings and inspected the machines and apparatus.

The results sought were: Delivery efficiency, power consumption and amount of cooling water used.

Orifice Test. The quantity of air delivered was measured by a battery of orifices connected to the main air line. These orifices were eight in number, ranging in diameter from 8/32 up to ⅝-in., and were made in plates ½ in. thick, connected to a manifold by ordinary globe valves. The orifices were countersunk with a 7/16-in. radius next the globe valves, so that the escaping air completely filled the orifices. The manifold was equipped with a thermometer well and tapped for a pressure gauge. In running the test, orifices were opened until the pressure was exactly maintained at a predetermined point. The maximum flow of air at the full pressure showed the delivery efficiency of the compressor.

The type of orifice used had been tested carefully, by the displacement tank method, and the quantity of air discharged agreed accurately with Fliegner's formula.

At 188 r.p.m., the Sullivan compressor filled two ⅝-in. orifices, two ½-in., and one 5/16-in. The piston inlet machine, at the same speed, filled two ⅝-in. orifices and two orifices ½ in. in diameter.

This gives an actual delivery capacity of 1,814 cu. ft. of free air for the Sullivan machine, or a delivery efficiency of 87.7%; and a delivery capacity of 1,676 cu. ft., or 79.1% delivery efficiency for the piston inlet compressor.

Readings on the latter machine were also taken at ¾, and ½ and ¼ load. The orifice test showed deliveries, respectively, of

1,153, 607 and 248 cu. ft. of free air per min., or ratios of delivery to piston displacement as follows: ¾ load, 54%; ½ load, 29%; ¼ load, 12%.

Deriviation of Delivery Ratios for Compressor. As the unloading device on the compressor was of the total closure pattern, the following figures are derived from full load and no load readings:

	Ft. air	Ratio of delivery to pis. disp.
Compressor running at full load ¾ time, ¼ time no load	1362	67%
Compressor running at full load ½ time, ½ time no load	907	44%
Compressor running at full load ¼ time, ¾ time no load	453	22%

Cooling Water. The temperature of the cooling water passing through the intercooler and cylinder jackets was taken at various points, and it was carefully weighed. On the Sullivan machine the intercooler circulation was 54 lbs. per min., and that through the cylinder jackets, 22 lbs., or a total of 76 lbs. The Sullivan machine therefore used ½ gal. per 100 cu. ft. of free air, as compared with 1 gal. for the piston inlet compressor.

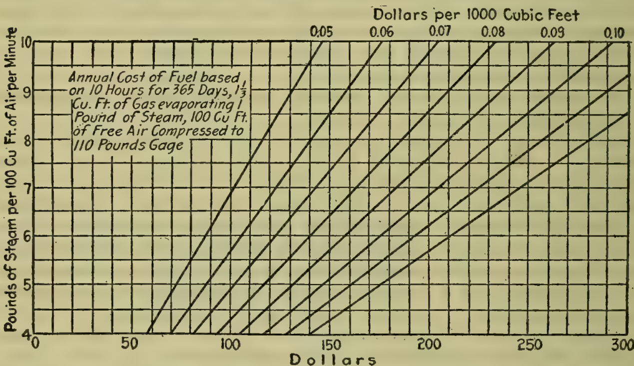


Fig. 1. Cost of fuel when using gas.

Steam Driven Air Compressor Economies. E. C. Sickles in Power, Nov. 28, 1911, states that during the past it has been the practice to give but little attention to the cost of operation in the medium-sized compressed-air plants, and in some cases this holds true for the larger plants. First cost has been the main consideration.

Single-stage machines compressing to 90 or 100 lbs. have been purchased with simple steam cylinders, operating at 125 lbs. steam pressure at the throttle. These have operated for years in localities where the fuel cost is high, and where difficulties were en-

countered, due to dust and carbonizing effects, with consequent losses in economy and explosions due to extremely high temperature conditions and troubles in lubrication.

Improvements have taken place more readily in the air end by the adoption of the 2-stage compressors, with consequent economy, due to intercooling, and ease of lubrication because of lower temperature. In the steam end, however, the most economical arrangement of cylinders and valves has not been followed generally, and there has been considerable loss in fuel economy and through investment for increased boiler plant.

Among steam-driven compressors which have been used to a large extent may be mentioned those employing the Meyer valve on the steam end. This type of valve is customarily used in conjunction with a throttling governor, controlled by air pressure. As the valves are hand set, under varying conditions of load with-

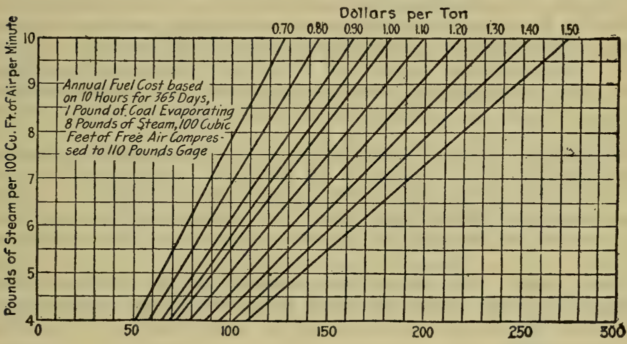


Fig. 2. Cost of fuel when using coal.

out constant attendance it becomes necessary to arrange the valves to cut off at a fixed point, necessarily so late as practically to eliminate all the economies which might be expected if the compressor were driven under fixed conditions and constant output. If the Meyer valves are set at an economical cutoff, and a heavy load comes upon the machine, it will stop, and the air supply may be cut off at considerable inconvenience. This type of valve, therefore, involves, under varying compressed-air demands, either a loss in economy or constant attendance. The well known throttling type of governor, which is the usual adjunct to this type of compressor, does not permit the highest steam economy.

It therefore becomes necessary, even where the fuel-supply cost per unit is low, if the most economical commercial results are to be obtained, to consider carefully not only the design of the compressor in detail, but also all the factors entering into the cost of the compressed air plant. In the cost of a new plant this would involve comparison of the cost of the necessary boiler capacity

installed, the cost of the compressor foundations, building and all other factors involved in the complete installation. The annual charges based upon the total cost of the compressor installed for the same capacity of output, added to the cost of fuel operation and maintenance cost, will give the proper basis for comparison and decision in the purchase of the most economical compressor.

Since an air compressor is to deliver a certain amount of free air, compressed to a certain pressure, it is desirable in securing bids that the steam consumption be obtained, based upon 100 cu. ft. of air compressed to the desired gage pressure.

In Figs. 1 and 2 are represented the annual fuel costs of compressed air based on 10 hrs. for 365 days when delivering 100 cu. ft. of free air compressed to 110 lbs. gage. Fig. 7 represents the cost when gas is used for fuel under the steam boilers, and Fig. 8 when using coal. The price of gas is taken as varying from 5 cts. to 12 cts. a thousand cu. ft., and the price of coal from 70 cts. a ton to $1.50 per ton. As a sample of what may be expected from a compressor of approximately 1,200 cu. ft. capacity, of compound noncondensing steam end with an economical valve gear and two-stage air end, it might be stated that the steam consumption per 100 cu. ft., compressed to 110 lbs. gage, is approximately 6.4 lbs. of steam.

Comparative Costs of Compressing Air by Steam and Electricity. The following data were given by William Thompson before the Canadian Mining Institute. The steam and electrically operated compressed air plants, from which the information was gathered, were located at Rossland, B. C., the power being used to operate mines.

Steam Plant. The steam plant consisted of two 250 h.p. Heine safety water tube boilers supplying steam at 150 lbs. pressure to 2 compound condensing Corliss 2-stage air compressors of the following dimensions:

Diameter	Inches
High press. steam cylinder	22
Low press. steam cylinder	36
High press. air cylinder	22
Low press. air cylinder, one compressor	36
Low press. air cylinder, other compressor	38
Length of stroke	48

In addition there were nine 125-h.p. steel shell tubular boilers, designed to operate the hoisting and surface plants, which could be connected if desirable.

Electrically Driven Air Compressing Plant was erected by the Rossland Great Western Mines, Limited, and was originally intended to be operated in connection with the steam plant previously described, the intention being to supply power from a central station to four mines, owned by different companies. The arrangement would have given each mine power at the lowest possible cost, and have ensured continuous operations by reason of the compressing plant being arranged in separate units. Each company

would pay its share of operation maintenance of plant, pro rata to its consumption of air.

When it was found necessary to erect the third unit to the compressing plant, unforeseen difficulties presented themselves in the shape of shortage of water for condensing and cooling purposes. On examination it was found that a satisfactory supply could not be secured without heavy capital expenditures for erection of flumes, etc., to convey the water to where it was required for use.

It was, however, found that a supply of water, barely sufficient for the intercoolers and waterjackets, was available about ¾ mile from the steam plant. By conserving this water supply, cooling and re-using, it was decided a sufficient supply of water for the air cylinder jackets and intercoolers could be secured.

Electrical Equipment. Three-phase, S.K.C., synchronous motor, designed for 2,200 volts, with rated capacity of 660 kws., equivalent to about 825 h.p. The motor is provided with a separate starting motor, mounted on the main frame, exciter and Italian marble switch-board, on which all operating switches and instruments are mounted.

There is a 50-in. Frisbee clutch set intermediate between the driving pulley and the motor. The motor is of a four bearing type, fitted with self-aligning and self-oiling sleeves. The entire machine is mounted upon a solid cast iron base set upon massive concrete foundations. The driving pulley is 60 ins. in diameter, grooved for 22½-in. ropes, and runs at 270 r.p.m.

All tests were conducted under the personal supervision of the writer, and extreme care was taken to arrive at actual facts. Indicator diagrams were taken off both the steam and air cylinders every half-hour, and the results tabulated. Coal consumed was weighed, and all other supplies, such as waste, oil, etc., charged as used.

Readings were also taken and recorded by means of a delicately adjusted kw. meter, connected to the primary mains, of the amount of electric power used. The test extended over a period of 30 days, without interruption, both plants being run under exactly similar conditions as to air pressure.

Each of the plants tested being modern and representative of their respective types, gave an opportunity for a comparative test that rarely falls to the lot of an individual engineer under such favorable conditions, as to work being performed, and for this reason is the more valuable as data for basing calculations as to problems of power.

The average results of the 30 days' test are recorded in Tables XIV and XV.

The saving shown in Table XV would be affected adversely if the electric plant was operated singly and the entire air compressed was not used, for the reason that electrically driven compressors must be operated at constant speed, and loss of air at safety valve would be considerably increased over the same loss at steam plant, which could be run at the speed required to compress the amount of air actually required. This loss would, how-

TABLE XIV. OPERATING COSTS OF STEAM AND ELECTRIC PLANTS

Work performed by steam plant:	
Average indicated h.p. at steam cylinders of the combined machines	730
Free air compressed per minute from atmospheric pressure to 95 lbs. per sq. in., cu. ft.	5,432
Free air compressed per hr.	325,920
Average h.p. required at steam cylinders to compress 100 cu. ft. of air per min. to gauge pressure	13.4
Pounds of coal consumed during test, lbs.	1,038,000
Pounds of coal consumed per day of 24 hours, lbs.	36,400
Average pounds of coal consumed per h.p. per hr. during test	1.9
Work performed by electric plant:	
Average h.p. registered at switchboard	540
Free air compressed per min. from atmospheric pressure to 95 lbs. gauge pressure, cu. ft.	3,319
Free air compressed per hour	199,140
Average h.p. required at motor to compress 100 cu. ft. of free air per min. to 95 lbs. gauge pressure	16.3
Cost of operating steam plant:	
Total cost of fuel consumed during test	$2,880.45
Total cost of wages for employees	710.00
Total cost of oils, waste, etc.	147.30
Total cost for 30 days, exclusive of maintenance and depreciation	$3,737.75
Cost per h.p. per month for fuel	3.96
Cost per h.p. per month for oil, etc.	0.20
Cost per h.p. per month for wages	0.97
	$5.13
Cost per h.p. per annum ....)	$61.56
Cost for each 100,000 cu. ft. of free air compressed	1.59
Cost per drill shift	1.27

NOTE: 80,000 cu. ft. taken as the average consumption per shift of one 3¾ in. drill.

Cost of operating electric plant:	
Cost of current for thirty days	$1,744.26
Cost of employees' wages	270.00
Cost of oils, waste, etc.	73.00
Total cost for 30 days, exclusive of maintenance and depreciation	$2,087.86
Average cost per h.p. per month	3.87
Average cost per h.p., per annum	46.44
Cost for each 100 000 cu. ft. of air compressed	1.46
Cost per drill shift	1.17

Note — 80,000 cu. ft. taken as the average consumption per shift of one 3¾-in. drill.

TABLE XV. COMPARATIVE RESULTS BETWEEN THE TWO TYPES OF COMPRESSORS

(Each 100,000 cu. ft. of air compressed from atmospheric pressure to 95 lbs. receiver pressure.)

Cost for each 100,000 cubic ft. of free air compressed by steam plant (Table XIV)	$1.56
Cost for each 100,000 cubic ft. of free air compressed by electric plant (Table XIV)	1.46
Result, saving by electricity over steam	6.4 per cent.

ever, be slightly offset by the increased cost per h.p. by working the steam compressors on underload.

Results obtained from the system of intercooling used on the compressors tested are noteworthy.

In Table XIV it is shown that the steam plant required 13.4 h.p. to compress 100 cu. ft. of air to 95 lbs. gauge pressure per min. The best power factor recorded that has come under the writer's notice, for doing the same amount of work by a two-stage compressor, is 14.5 h.p., which shows a saving of 8% resulting from the use of specially designated intercoolers, for which the manufacturers are entitled to receive the credit.

How this result is obtained can be best understood by reproducing the average of a number of tests made on the efficiency of the intercooler during the progress of the power test. The results of the tests are as follows:

	Degs. F.
Temperature of cooling water at inlet of intercooler......	42
Temperature of cooling water at outlet of intercooler......	50
Rise in temperature of cooling water while passing through intercooler	8
Temperature of air at outlet of low pressure cylinder and before passing through intercooler	196
Temperature of air at inlet of high pressure cylinder after passing through intercooler	54
Reduction in temperature of air after passing through intercooler	142

Cost of Compressing Air at a Large Plant in Utah. The following data on the cost of operating a large cross compound, 2-stage compressor plant in Utah is given in a letter to the authors by F. Charles Merry. Approximately one hundred million cu. ft. of free air were compressed per month.

Power house labor:	Per 1000 cu. ft.
At average Utah rates for 1914..........	$0.0052
Repair and maintenance labor	0.0012
Fuel (slack coal at average Utah prices)..........	0.0192
Other supplies	0.0019
Total operating cost	$0.0275
Lbs. coal per 1000 cu. ft.	9.33

The above is the average of 6 months' operation and represents the best work done with the plant up to that time.

Panama Air Compressor Lubrication. The following report of the use of lubricating oils in the three air-compressor plants of the Isthmian Canal Commission for the month of February, 1911, is from a letter by D. E. Irwin published in Power. It shows the number of revolutions, sq. ft. covered per pint of oil, output in cu. ft. of air and the cost per million sq. ft. covered.

In the air-compressor plants at Empire, Las Cascadas and Rio Grande were 14 compressors, each of 425 h.p. and all operating at a steam pressure of 125 lbs. The engines were simple twin cylinder; the compressors were of the double-cylinder cross-compound type. The area of the two steam cylinders was 9.42 sq. ft.;

TABLE XIV. COMPRESSOR LUBRICATION AT PANAMA

Oils used:	Empire air compressor	Las Cascadas air compressor	Rio Grande air compressor
Valve oil, gal.	87¾	22	38
Stationary engine oil, gal.	157¾	35	60
Air compressor cylinder oil, gal.	87¾	23	45
Revolutions per gal. of valve oil	236,458	295,655	217,650
Revolution per gal. of stationary-engine oil	131,532	185,840	137,845
Revolutions per gal. of air-compressor cylinder oil.	236,458	282,800	183,682
Sq. ft. covered per pint of valve oil	1,041,107	1,392,597	1,025,122
Sq. ft. covered per pint of air-compressor cylinder oil	1,354,971	1,837,513	1,028,152
Cost per million sq.-ft. covered (surface):			
Valve oil	$0.0234	$0.0175	$0.0237
Air-compressor cylinder	$0 0134	$0.0098	$0 0176
Output of free air, cu.-ft.	378,879,661	118,770,526	151,205,582

the area of the low-pressure air cylinders, 15.17; the area of the high-pressure cylinders, 9 42 sq. ft. The speed of these compressors was from 127 to 137 r.p.m.

Efficiency of Compressed Air Transmission. Snowden B. Redfield in American Machinist states that in nearly all cases compressed air is used in some form of reciprocating cylinder without expansion; indeed if expansion were allowed (unless reheating is resorted to) while the air could then give up more work, the moisture always present in the air would quickly freeze, choking the exhaust ports and passages of the machine with ice.

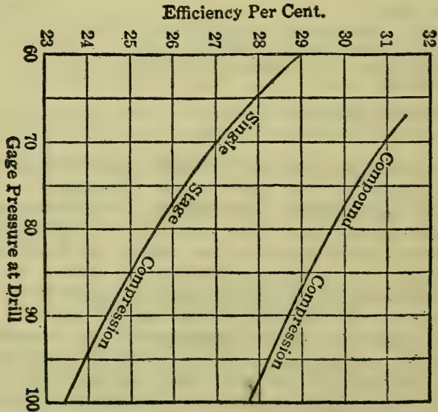


Fig. 3. Probable efficiency referred to air end of compressor.

As examples of machines using air with little or no expansion, rock drills and pneumatic tools may be cited, and some interesting figures as to the efficiency of the power transformation are given by the accompanying diagrams.

Indicator diagrams of such machines would theoretically be rectangles, but wire drawing and cushioning effects of the valve mechanism would considerably modify this. It may be assumed then, reasoning from such a thing as a steam pump cylinder, without cutoff, that the diagram factor will be about 80%. In other words the actual mean effective pressure will be about 80% of what the theoretic rectangular diagram would give.

On this basis it is determined that a standard rock drill having a 3-in. diameter cylinder will develop about 6.2 indicated h.p. with

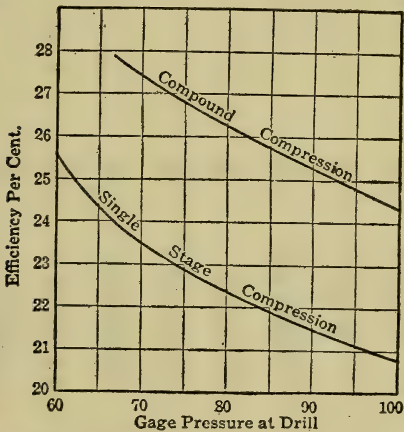


Fig. 4. Probable efficiency referred to steam end of compressor.

100 lbs. at the throttle, this decreasing with the pressure supplied, down to about 3.7 i.h.p. with only 60 lbs. pressure.

A 3-in. rock drill will require about 138 cu. ft. of free air per min., with 100 lbs. pressure at the throttle; this decreasing to 90 cu. ft., with only 60 lbs. pressure.

Knowing the quantity of air and the pressure, the compressor h.p. is easily calculated.

Thus, allowing 10 lbs. pressure drop in the pipe, a 3-in. rock drill will require 29.8 i.h.p. in the steam cylinders of the compressor with 100 lbs. pressure and single-stage compression, or 25.2 i.h.p. with compound compression. These figures reduce as the pressure used is reduced, but this, of course, reduces the work done by the tool.

Comparing the probable i.h.p. developed inside the drill cylinder with the actual compressor power required to furnish the air, gives

TABLE XV. SHOWING LOSS IN PRESSURE, IN POUNDS, DUE TO FRICTION IN PIPES 100 FEET IN LENGTH — GAUGE PRESSURE AT ENTRANCE TO PIPE, 75 LBS.

CUBIC FEET FREE AIR DELIVERED PER MINUTE

Diam. pipe	25	50	75	100	125	150	200	250	300	350	400
1	.38	1.51	3.4	6.05	...	...	...	...	...	...	...
1¼	.11	.42	.95	1.69	...	...	...	...	...	...	...
1½	...	.16	.37	.65	1.02	1.46	2.6	...	...	...	...
2	...	.04	.08	.14	.22	.32	.56	.88	1.26	1.72	2.25
2½	...	...	...	.04	.07	.1	.17	.27	.39	.53	.69
3	...	...	...	...	...	.04	.06	.1	.15	.2	.26
3½	...	...	...	...	...	...	...	...	.07	.09	.12
4	...	...	...	...	...	...	...	...	...	...	.06
4½	...	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...	...	...	...	...

Diam. pipe	500	600	700	800	900	1000	1200	1500	1800	2000	2500
1	...	...	...	...	...	...	...	...	...	...	...
1¼	...	...	...	...	...	...	...	...	...	...	...
1½	...	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...	...
2½	1.08	1.55	2.11	2.76	...	...	...	...	...	...	...
3	.4	.58	.79	1.03	1.3	1.61	2.32	...	...	...	...
3½	.18	.26	.36	.47	.59	.73	1.05	1.65	...	...	...
4	.09	.13	.18	.23	.29	.36	.52	.81	1.17	1.44	2.26
4½	.05	.07	.1	.13	.16	.2	.29	.45	.65	.8	1.25
5	...	.04	.05	.07	.09	.11	.16	.25	.36	.44	.69
6	...	...	...	.03	.04	.05	.06	.1	.15	.18	.28
7	...	...	...	...	...	.02	.03	.05	.07	.08	.13
8	...	...	...	...	...	...	...	.02	.03	.04	.06
10	...	...	...	...	...	...	...	...	...	.01	.02
12	...	...	...	...	...	...	...	...	...	...	...

Diam. pipe	3000	3500	4000	5000	6000	7000	8000	9000	10000
1	...	...	...	...	...	...	...	...	...
1¼	...	...	...	...	...	...	...	...	...
1½	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
2½	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...
3½	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...
4½	1.81	...	...	...	...	...	...	...	...
5	1.	...	...	...	...	...	...	...	...
6	.4	.55	.72	...	...	...	...	...	...
7	.18	.25	.32	.5	.73	...	...	...	...
8	.09	.13	.16	.26	.37	.5	.66	...	...
10	.03	.04	.05	.08	.12	.16	.21	.27	.33
12	.01	.02	.02	.03	.05	.07	.09	.11	.14

TABLE XVI. SHOWING LOSS IN PRESSURE, IN POUNDS, DUE TO FRICTION IN PIPES 100 FEET IN LENGTH. GAUGE PRESSURE AT ENTRANCE TO PIPE, 90 LBS.

CUBIC FEET FREE AIR DELIVERED PER MINUTE

Diam. pipe	25	50	75	100	125	150	200	250	300	350	400
1	.33	1.3	2.93	5.19	...	...	...	...	...	...	...
1¼	.09	.36	.81	1.44	...	...	...	...	...	...	...
1½	...	.14	.31	.56	.87	1 25	2.23	...	...	...	...
2	...	.03	.07	.12	.19	.27	.48	.76	1.09	1.48	1.94
2½	...	...	...	.04	.06	.08	.15	.23	.33	.45	.59
3	...	...	...	...	...	.03	.06	.09	.13	.17	.22
3½	...	...	...	...	...	...	...	...	.06	.08	.1
4	...	...	...	...	...	...	...	...	...	...	.05
4½	...	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...	...	...	...	...

Diam. pipe	500	600	700	800	900	1000	1200	1500	1800	2000	2500
1	...	...	...	...	...	...	...	...	...	...	...
1¼	...	...	...	...	...	...	...	...	...	...	...
1½	...	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...	...
2½	.92	1.33	1.81	2.36	...	...	...	...	...	...	...
3	.35	.5	.68	.89	1.12	1.39	2.	...	...	...	...
3½	.16	.23	.3	.4	51	.63	.9	1.41	...	...	...
4	.08	11	.15	.2	.25	.31	.45	.7	1.	1.24	1.93
4½	.04	.06	.08	.11	.14	.17	.25	.39	.56	.69	1 07
5	...	.04	.05	.06	.08	.1	.14	.22	.32	.39	.61
6	...	...	...	.02	.03	.04	.06	.09	.12	.15	.24
7	...	...	...	...	...	.02	.03	04	.06	.07	.11
8	...	...	...	...	...	...	...	.02	.03	.04	.06
10	...	...	...	...	...	...	...	...	...	.01	.02
12	...	...	...	...	...	...	...	...	...	...	...

Diam. pipe	3000	3500	4000	5000	6000	7000	8000	9000	10000
1	...	...	...	...	...	...	...	...	...
1¼	...	...	...	...	...	...	...	...	...
1½	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
2½	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...
3½	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...
4½	1.54	...	...	...	...	...	...	...	...
5	.88	...	...	...	...	...	...	...	...
6	.35	.47	.61	...	...	...	...	...	...
7	.16	.21	.28	.44	.63	...	...	...	...
8	.08	.11	.14	.22	.32	.43	.57	...	...
10	.03	.03	.05	.07	.1	.14	.18	.23	.28
12	.01	.01	.02	.03	.04	.05	.07	.09	.11

TABLE XVII. SHOWING LOSS IN PRESSURE, IN POUNDS, DUE TO FRICTION IN PIPES 100 FEET IN LENGTH. GAUGE PRESSURE AT ENTRANCE TO PIPE, 100 LBS.

CUBIC FEET FREE AIR DELIVERED PER MINUTE

Diam. pipe	25	50	75	100	125	150	200	250	300	350	400
1	.3	1.18	2.66	4.75	...	...	...	...	...	...	...
1¼	.08	.33	.73	1.3	...	...	...	...	...	...	...
1½	...	.13	.29	.6	.8	1.15	2.04	...	...	...	...
2	...	.03	.07	.12	.18	.26	.47	.73	1.05	1.43	1.87
2½	...	...	...	.03	.05	.08	.14	.21	.31	.42	.54
3	...	...	...	...	...	.03	.05	.08	.11	.15	.2
3½	...	...	...	...	...	...	...	...	.05	.07	.09
4	...	...	...	...	...	...	...	...	...	...	.05
4½	...	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...	...	...	...	...

Diam. pipe	500	600	700	800	900	1000	1200	1500	1800	2000	2500
1	...	...	...	...	...	...	...	...	...	...	...
1¼	...	...	...	...	...	...	...	...	...	...	...
1½	...	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...	...
2½	.85	1.22	1.66	2.17	...	...	...	...	...	...	...
3	.31	.45	.61	.8	1.01	1.25	1.8	...	...	...	...
3½	.14	.21	.28	.37	.46	.57	.82	1.28	...	...	...
4	.07	.1	.14	.18	.23	.28	.41	.64	.92	1.13	1.77
4½	.04	.06	.08	.1	.13	.16	.23	.35	.51	.63	.98
5	...	.03	.04	.06	.07	.09	.13	.2	.29	.36	.56
6	...	...	...	.02	.03	.04	.05	.08	.11	.14	.22
7	...	...	...	...	...	.02	.02	.04	.05	.06	.1
8	...	...	...	...	...	...	...	.02	.33	.03	.05
10	...	...	...	...	...	...	...	...	...	.01	.02
12	...	...	...	...	...	...	...	...	...	...	...

Diam. pipe	3000	3500	4000	5000	6000	7000	8000	9000	10000
1	...	...	...	...	...	...	...	...	...
1¼	...	...	...	...	...	...	...	...	...
1½	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
2½	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...
3½	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...
4½	1.41	...	...	...	...	...	...	...	...
5	.81	...	...	...	...	...	...	...	...
6	.32	.43	.56	...	...	...	...	...	...
7	.14	.2	.25	.4	.57	...	...	...	...
8	.07	.1	.13	.2	.29	.39	.51	...	...
10	.02	.03	.04	.06	.09	.13	.16	.21	.26
12	.01	.01	.02	.02	.04	.05	.06	.08	.1

the probable efficiencies shown by the chart. These efficiencies are referred to both the air and steam cylinders of the compressor, so as to give a basis for calculations for various methods of driving the compressor. They include 10 lbs. pressure drop in the pipe line.

Referred to the air end of the compressor, it is thus seen that with single stage compression and 100 lbs. pressure, about 23.5% efficiency is obtained, increasing to about 29% with the low pressure of 60 lbs. Compound air compression brings these figures up to 27.8% with 100 lbs. and 31% with 70 lbs.

Referred to the steam end, allowing 88% mechanical efficiency between the steam and air ends of the compressor, single-stage compression gives a little less than 21% efficiency with 100 lbs. and about 25.5% with 60 lbs. air pressure. Compounding the air cylinders of the compressor increases these figures to about 24.5% with 100 lbs. and almost 27½% with 70 lbs. air pressure.

While these figures for efficiency have been determined for rock drills in particular, they apply equally well to almost any machine using compressed air without expansion. It must, however, be remembered that the figures are based upon i.h.p. only, both in the drill and the compressor. This is because of the impracticability of measuring the brake h.p. of the drill. If, however, brake h.p. efficiency is required, these figures for efficiencies of i.h.p. can be multiplied by the mechanical efficiency of the device using the air, say 90% or 80%, as the case may be. This, of course, gives a still smaller result.

It is to be noted that the higher efficiencies are obtained with the lower pressures. This is because there is less loss by heating the air during compression, and therefore it is advisable to use pressures as low as is consistent with the size and weight of the machine required to do a given amount of work.

Methods and Cost of Laying 6-in. and 8-in. Wrought-Iron, Screw-Joint Pipe for a Compressed Air Main. E. E. Harper in Engineering News, Feb. 27, 1908, states that the work consisted of laying 7,000 ft. of 8-in. and 4,000 ft. of 6-in. wrought-iron, screw-joint pipe for a compressed air line carrying 80 to 90 lbs. pressure. The work was all performed by common labor, none of the men being experienced in pipe laying.

The greatest cause of delay in laying screwed pipe is the difficulty in getting each successive length of pipe into line and keeping it there until the first threads take hold and the pipe begins to screw together. To overcome this difficulty a cradle for supporting the pipe at the joint, a jack for adjusting and supporting the outer end of the pipe and a straight-edge for lining the pipe were devised. The cradle holds the threaded end of the pipe in position to enter the sleeve coupling on the last joint laid; the jack allows both vertical and horizontal adjustment of the joint of pipe; and the straight-edge shows when the pipe is in line ready to screw together. The cradle was simply a wood block, 8 by 8 ins. by 24 ins. in length, with a groove having a 4-in. radius cut in its top. The jack is shown by Fig. 5 and the straight-edge by Fig. 6. The movable block on the straight-edge is necessary because

it is almost impossible to make a 12-ft. straight-edge that will remain true for more than a day.

These devices saved fully 50% over the crude and unsatisfactory method of using blocks to hold the pipe in line. There was no straining and lifting to hold the pipe in place, and as the pipes were started together straight there were no stripped threads and bad joints, and the pipe made up so easily that one man with a pair of 3-ft. tongs often screwed an 8-in. pipe half way up; it was then completed by four men using two pairs of tongs with 8-ft. handles.

The threads, both male and female, were cleaned with wire brushes. Dixon's pipe joint compound was used on all screwed joints. Ring gaskets of 1/16-in. Rainbow packing were used on flange joints, the gasket being pasted to one flange with coal-tar roofing paint, which held it in position while the joint was being made.

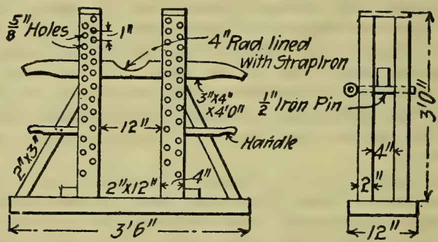


Fig. 5. Jack for holding end of pipe.

Six-Inch Pipe Line. The total length of 6-in. pipe was 4,118 ft. The pipe was 6-in. lap welded casing weighing 15 lbs. per lin. ft. It was laid with sleeve couplings, 11½ threads per in., with a flange union every 150 ft. and U-bends for expansion every 500 ft. The average length of joints was 20.1 ft.; an average of 588.2 ft. of pipe or of 29.3 joints, was laid per 10-hr. day. The best day's work was 1,065 ft., or 53 joints, with 6 men working 9 hrs., making 177.5 ft. per man; the poorest day's work was 120 ft., or 6 joints, by 6 men working 9½ hrs. The work was done from Aug. 15 to 24, 1907, in fair weather except for one day when the men worked 4 hrs. in rain and laid 22 joints. The men walked 2½ to 3 miles to and from work. The average gang was: 4.85 men at 20 cts. per hr., 1 foreman at 30 cts. per hr., and 1 waterboy at 10 cts. per hr. The cost of pipelaying was as follows per 100 ft.:

Items.	Per 100 ft.
Clearing right of way	$0.327
Hauling and distributing	1.578
Blocking to grade	0.116
Constructing bents	0.450
Anchors for U-bends	2.290

Items.	Per 100 ft.
Painting	0.900
Tools	0.100
Testing	0.300
Laying	3.137
Surveying and superintendence	0.700
Total	$9.898

The total cost per ft. exclusive of cost of pipe was 9.898 cts., or, say, 10 cts. The following notes explain the work included in the various items:

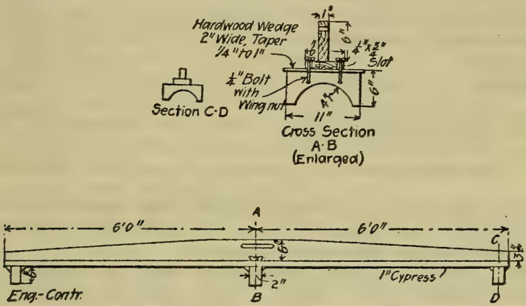


Fig. 6. Straight edge used in cementing the pipe.

Clearing. Removing small brush for a width of 10 ft.

Hauling. The average hauls was 3,000 ft. over bad roads, steep and rough. This item includes loading pipe on cars and unloading, hauling and distributing, including seven U-bends. Teams and drivers got $3 per day.

Blocking. Includes temporary blocking and bending pipe in five places by building fires on it.

Anchors for U-Bends. Includes 8 piers at $12 each, including bolts and clamps.

Bent Construction. Includes carpenter work only on about 20 bents, averaging 3 ft. in height and made of 4 by 6-in. stuff.

Painting. Includes cost of painting and cleaning pipe with wire brushes with paint costing $1 per gal. and labor at 20 cts. per hr. The pipe was painted one coat

Tools. Includes shopwork and depreciation.

Eight-Inch Pipe Line. The total length of 8-in. pipe was 7,101 ft. The pipe was 8-in. O. D., lap-welded casing weighing 20 lbs. per ft., laid with sleeve couplings, 11½ threads per in. The average length of joints was 19.15 ft. There was a flange union every 150 ft. and U-bends for expansion every 600 ft. An average of 503.6 ft. was laid per day, of 10 hrs., or 26.3 joints. The best day's work was 613 ft., or 32 joints, by 6 men, including foreman; the poorest day's work was 380 ft., or

20 joints, by 7 men, including foreman. The work was done from July 2 to Aug. 5, 1907, the weather being hot and sultry, the thermometer ranging from 85 degs. to 100 degs. and averaging 90 degs. in the shade. The average gang was: 5.9 men at 20 cts. per hr., 1 foreman at 30 cts. per hr, and 1 waterboy at 10 cts. per hr. The cost was as follows per 100 ft.:

Items.	Per 100 ft.
Surveying and superintendence	$1.000
Laying	3.580
Clearing	0.187
Hauling and distributing	1.032
Blocking to grade	1.110
Constructing bents	1.069
Anchors for U-bends	2.535
Painting	1.200
Tools	0.102
Testing	0.388
Total cost of laying	$12.203
Cost of pipe	76.400
Grand total cost	$88.603

The total cost per ft., exclusive cost of pipe, was thus 12.2 cts., and including cost of pipe 88.6 cts. The following notes explain the work included in the various items:

Clearing. Removing small brush for a width of 10 ft.

Hauling. Includes 12 U-bends, which cost $1 each to haul; teams and drivers 30 cts. per hr., laborers 20 cts. per hr., and foreman 30 cts. per hr.

Bent Construction. Includes carpenter work only on about 80 bents of 4 by 6-in. stuff, spaced 30 ft. apart and ranging in height from 1 ft. to 16 ft., averaging 6 ft. high.

Anchors for U-Bends. Includes 12 piers at $15 each, including bolts and clamps.

Painting. Same as for 6-in. pipe.

Testing. Includes laying and connecting 200 ft. of 4-in. pipe to pump line. Tested to 110 lbs. hydraulic pressure. Leaks developed in two tees in line and these were repaired, line tested again and found tight.

Cost of Pipe. Cost f. o. b. McKeesport, Pa., $76 per 100 ft. (ton); freight from McKeesport to Flat River 40 cts. per ton (100 ft.).

Profit in Reheating. The following data from Compressed Air give the results of a test made in the shops of the Hansell Elcock Co., Chicago, in driving 1,608 ¾-in. rivets. Half of these rivets were driven using an ordinary air line, and half were driven using heated air from a Sterling Heater.

A plain toggle portable yoke riveter was used. The compressor cylinder was 10 ins. in diameter and 9½ in. stroke.

An Excelsior Airometer was put in the line, at which point line pressures and line temperatures were read. Twenty ft. of 1-in. rubber hose was used between the airometer and the Sterling heater. On the discharge side of the heater a gage and ther-

mometer were inserted for reading the temprature and pressure of the heated air. Between the heater and the riveter 27½ ft. of 1-in. insulated flexible hose was used. The following shows the results:

	Without heater	With heater
Number of rivets	804	804
Ave. temp. of line air	57.5 deg.	60.0 deg.
Average pressure, lbs.	85	85
Total cu. ft. air used	14,874	8,513
Ave. temp. of heated air	...	396 deg.
Cu. ft. air used per rivet	18.5	10.58

This difference in air used per rivet equals 7.92 cu. ft. or an increase in volume of 74.7%. This increase equals an actual saving in air used of 42.7%.

Assuming 1,500 rivets per day, the actual air saving equals 11,880 cu. ft. At 8 cts. per 1,000 cu. ft. this saving equals 95 cts., the cost of operating the heater equals 1 gal. oil at 10 cts. plus 8 cts. for ignition current equals 18 cts., total, a net saving of 77 cts. per day. This saving 6 days per week would pay for the heater in one year and leave a profit of $156.

The cu. ft. of air given were actual airometer readings. On account of the intermittent service the heated air temperatures are not quite high enough. The actual temperature of the air supplied to the riveter was about 15% in excess to the heated air temperatures shown in the table.

TABLE XVIII. AIR USED IN CUBIC FEET FREE AIR PER MINUTE PER INDICATED HORSE-POWER IN MOTORS WITHOUT REHEATING

(From Hiscox's Compressed Air)

Point of cut-off	Gauge pressures in pounds 40	60	80	100	125	150
1	21.3	19.4	18.42	17.8	17.40	17.05
¾	17.1	15.47	14.6	14.15	13.78	13.50
⅔	16.2	14.50	13.75	13.28	12.90	12.60
½	14.5	12.8	11.93	11.48	11.10	10.85
⅓	15.2	11.85	10.8	10.21	9.78	9.50
¼	15.6	13.3	10.72	10.0	9.42	9.10

Air Used per Motor Horsepower. As will be seen from Table XVIII, the only data required are the gauge pressure and point of cut-off; given those two items, we find from the table the free air required per i.h.p., and it will only be necessary to multiply this amount by the total i.h.p. of the motor to determine the total quantity of free air required, and consequently the necessary size of an air compressor to furnish the required amount of air.

These figures do not take account of clearance, but it will be an easy matter to add the per cent. of clearance after having determined the total amount of free air required.

It will also be notice that the free air consumption is based upon the use of cold air, i. e., initial temperature of air at 60 degs. F.

In case reheating is resorted to there will be a corresponding decrease in the amount used, dependent upon the temperature of air on admission to motor, and will be proportional to the ratio of $\frac{T_2}{T_3}$ where $T_2 = 460 + 60 = 520$ degs. F. absolute temperature and $T_3 = 460$ plus temperature of air at admission to motor.

Thus, if the air is reheated to 300 degs. F., the quantity in the table will have to be multiplied by

$$\frac{460 + 60}{460 + 300} = \frac{520}{760} = .684$$

A further use of this table is to find the most economical point of cut-off for gauge pressures from 30 lbs. to 150 lbs. per sq. in. This fact is apparent from a study of each vertical column; thus, at 60 lbs. pressure the lowest consumption of free air per i.h.p. is at ⅓ cut-off, while at 40 lbs. pressure the most economical cut-off will be ½.

To find the quantity of free air required per min., in a direct acting steam pump, to raise a given number of gals. of water through a given head, divide the diameter of the air cylinder by the diameter of the water cylinder, and under the heading of this ratio in above table, and to the right of the given head or lift, find

TABLE XIX. VOLUME OF AIR AND PRESSURE REQUIRED TO DRIVE DIRECT ACTING STEAM PUMPS. (From Hiscox's Compressed Air)

	Gauge pressure in pounds per square inch					Cubic feet of free air per minute to lift one gallon of water				
	Ratio of cylinder diameters					Ratio of cylinder diameters				
Head of water in feet	1 to 1	1½ to 1	2 to 1	2½ to 1	3 to 1	1 to 1	1½ to 1	2 to 1	2½ to 1	3 to 1
10	6					.22				
20	11					.28				
30	16	7				.33	.53			
40	21	9				.38	.58			
50	26	12	7			.44	.65	.94		
60	31	14	8			.49	.70	.99		
70	36	16	9			.54	.75	1.03		
80	42	18	11			.61	.79	1.11		
90	47	21	12			.66	.87	1.15		
100	52	23	13			.72	.91	1.20		
125	65	29	16	10		.86	1.06	1.33	1.67	
150	78	35	20	13	9	1.00	1.20	1.50	1.88	2.31
175	90	40	23	15	10	1.12	1.32	1.63	2.00	2.40
200	105	46	26	17	12	1.28	1.47	1.75	2.14	2.60
250	...	58	33	21	15		1.75	2.06	2.41	2.89
300	...	68	39	25	17		2.00	2.31	2.68	3.08
350	...	80	45	29	20		2.28	2.57	2.95	3.37
400	...	92	52	33	23		2.57	2.87	3.22	3.66
450	...	105	58	37	26		2.88	3.13	3.48	3.95
500	...	...	65	42	29			3.42	3.82	4.24
600	...	...	78	50	35			4.00	4.35	4.80
700	...	...	92	60	42			4.58	5.00	5.50
800	...	...	105	67	47			5.15	5.50	5.96
900	...	...	...	75	52				6.00	6.45
1000	...	...	...	85	58				6.70	7.00

the cu. ft. of free air per gal. required per min.; this constant, multiplied by the total number of gals. to be lifted, will give the quantity of free air required. The gauge pressure for the corresponding conditions may be found in a similar manner under the heading of gauge pressures.

In the foregoing table of pressures an allowance of 15% has been made for pump friction, and in the table of volumes 15% has also been allowed for clearance losses and leakage. If the air is reheated before admission to air cylinder, the quantity may be reduced in proportion to the ratio of absolute temperatures. For

TABLE XX. AIR CONSUMPTION OF VARIOUS INDUSTRIAL TOOLS AND MACHINES

Tools	Size	Pressure in lbs. per sq. in.	Air consumed, free air per min. (cu. ft.)
Aerons (paint sprays)	Small hand, lbs.	90	2–3
	5	90	6
	7	90	10
	8	90	12
Chipping hammers classed by weight	9	90	13
	10	90	15
	11	90	17
	12	90	18
	13	90	20
	14	90	20
	18	90	22
Foundry jolting machines	Platform type	80	Air per ton lifting capacity 30–40
Grinders (hand)	20 lbs.	80	20
Hoists direct lift (2 to 1 lift)	(Cylinder diam. inch)		(Air in cu. ft. per ft. lift)
	6	80	.79
	8	80	1.45
	10	80	2.15
	12	80	3.31
	14	80	4.65
	17	80	6.6
	19	80	8.1
Hoists (4 to 1 lift)	6	80	.39
	8	80	.72
	10	80	1.52
	12	80	1.65
	14	80	2.37
	17	80	3.30
	19	80	4.05
Geared hoists capacity in tons	(Tons)		
	1	80	3
	1½	80	5
	2	80	6
	3	80	8
	4	80	10
	5	80	15
	6	80	20
	8	80	25
	10	80	30
	12½	80	40

Air consumption is shown in terms of "Free Air."

compound pumps the consumption may be assumed at 75% of the best results of the above table.

Air and Power Requirements of Pneumatic Hammers. In Tables XXI and XXII are given the actual cu. ft. of free air required per min. and the power to operate from one to fifty pneumatic hammers of the cylinder diameters and strokes shown. The quantities of free air for one tool have been obtained by careful experimenters with special water-displacement apparatus, and being the averages of a great many readings, may be taken as accurate and fairly representative for most tools of similar dimensions. The figures for more than one tool were obtained by deducting 2% for every five tools; that is, five chipping hammers are assumed to require 4.8 times as much air as one chipping hammer of equal size. Ten hammers are assumed to require 9.6 times as much as one hammer, and so on. This is to allow for the intermittent action of different tools in a shop, and this basis of calculation agrees very nicely with observed shop practice.

Figures for air are for 80 lbs. pressure at sea level, and are based on ordinary intermittent service as is usual in any shop. Ratings for one hammer are actual readings from water displacement tests, being averages of many trials.

Horsepower figures assume compound air compression to 85 lbs. pressure and include friction. For single stage compression to 85 lbs. add 15% to power figures. Compressor displacement required should include volumetric loss as figures are for actual air delivered.

The quantities of air, as shown by the larger figures in the table, are actual cu. ft. of free air required at atmospherice pressure at sea level, this air being delivered to the tool at 80 lbs. pressure. The figures for h.p., which are the smaller figures in the table, assume compound compression to 85 lbs. pressure; that is, allowing 5 lbs. drop in the pipe line. The figures for power also include reasonable friction of the compressor and the usual losses of power in the air cylinder of an air compressor of reasonably good design. They would represent just about the brake h.p. required from an electric motor to drive a compressor actually delivering the quantity of air given by the large figures above them.

This brings up the point of the volumetric efficiency of the compressor. As the quantities shown were obtained by actual measurement of air used, it is imperative that the output of the compressor shall be equal to this. To allow for volumetric efficiency loss, this necessitates that the piston displacement of the compressor shall be greater than these figures by from 8 to 12%, depending upon its design. The figures for power required include this loss, as they represent the power necessary to actually deliver the quantities of air shown as the actual output of the compressor.

In cases where single-stage compression is used the power required may be obtained by adding about 15% to the power figures given. This, of course, has no effect upon the air quantity.

It has been stated that these figures are for sea-level operation.

TABLE XXI. PNEUMATIC HAMMER AIR CONSUMPTION

Number of tools	1	5	10	15	20	25	30	35	40	45	50
Chipping hammers —											
Diameter stroke:											
1⅛ ins. by 1 in......	14	69	134	197	258	315	370	421	470	517	560
1⅛ ins. by 2 ins.....	17	18	163	240	313	383	449	512	571	627	680
1⅛ ins. by 3 ins.....	20	98	192	282	368	450	528	602	672	738	800
1⅛ ins. by 4 ins.....	22	108	211	310	405	495	581	662	739	812	880
1⅛ ins. by 5 ins.....	25	123	240	353	460	560	660	753	740	923	1000
Riveters:											
1$\frac{3}{16}$ ins. by 6 ins.....	33	162	317	465	607	743	875	993	1109	1218	1320
1$\frac{3}{16}$ ins. by 8 ins.....	36	176	346	508	662	810	950	1084	1210	1328	1440
1$\frac{3}{16}$ ins. by 9 ins.....	38	186	365	536	699	855	1003	1144	1277	1402	1520

Figures for air are for 80 lbs. pressure at sea level, and are based on ordinary intermittent service as is usual in any shop. Ratings for one hammer are actual readings from water displacement tests, being averages of many trials.

TABLE XXII. PNEUMATIC HAMMER POWER CONSUMPTION

Number of tools	1	5	10	15	20	25	30	35	40	45	50
Chipping hammers—											
Diameter stroke:											
1⅛ ins. by 1 in.....	2.6	13	25	37	48	59	69	79	88	96	104
1⅛ ins. by 2 ins.....	3.2	16	30	45	58	71	84	95	106	117	127
1⅛ ins. by 3 ins.....	3.7	18	36	52	69	84	98	112	125	137	149
1⅛ ins. by 4 ins.....	4.1	20	39	58	75	92	108	123	138	151	164
1⅛ ins. by 5 ins.....	4.7	23	45	66	86	105	123	140	156	172	186
Riveting hammers:											
1$\frac{3}{16}$ ins. by 6 ins.....	6.1	30	59	87	113	138	162	185	206	227	246
1$\frac{3}{16}$ ins. by 8 ins.....	6.7	33	64	95	123	151	177	202	225	247	268
1$\frac{3}{16}$ ins. by 9 ins.....	7.1	35	68	100	130	159	187	213	238	261	283

Horsepower figures assume compound air compression to 85 lbs. pressure and include friction. For single stage compression to 85 lbs. add 15% to power figures. Compressor displacement required should include volumetric loss, as figures are for actual air delivered.

This will be satisfactory for most localities, but at 5,000 ft. elevation 17% more free air capacity will be required and about 7% more h.p. for the same size and number of tools. These increases are practically proportional to the altitude. (S. B. R., in American Machinist.)

Compressed Air and Pneumatic Tools in the Foundry. W. H. Armstrong in Compressed Air Magazine, June, 1913, says that of the various pneumatic apparatus in the foundry it may perhaps be proper to speak first of the air hoist, as that is used in so many places and for such a variety of service throughout the works.

The most common types of air hoists are simple cylinders lifting direct or horizontal cylinders with or without multiplying shieves to reduce the length. The motor geared type of hoist is being largely adopted for much of the service where the single cylinders have been used, and especially for heavy traveling on jib cranes. Hoists of either type may often be applied to hand power cranes already in use without in the least interfering with the existing gearing, and at small expense. In the air hoist the power is applied to the load in the most direct and simplest manner. With this aid a boy can lift a given load a dozen times while a gang of men would be operating a chain block or a windlass. There is no noise, no jar and the load is always sustained. In foundries where an overhead traveler cannot be installed, air hoists suspended from trolleys running on a track are very satisfactory.

TABLE XXIII. COST OF PNEUMATIC HOISTING

Diam. of of cyl.	Effective area of piston	Maximum weight lifted	Cu. ft. of free air per 4-ft. lift	Cost of air per 100 lifts
2	3.05	274	0.74	$0.0037
3	6.87	618	1.67	.0084
4	12.22	1099	2.97	.0149
5	19.09	1718	4.64	.0232
6	27.49	2444	6.68	.0334
7	37.42	3367	9.09	.0455
8	48.87	4398	11.88	.0594
9	61.85	5566	15.03	.0752
10	76.36	6872	18.56	.0928
11	92.39	8315	22.46	.1123
12	109.96	9896	26.73	.1337

Cost of Air Hoisting. Few realize how cheaply an air hoist is operated, besides its convenience and speed in handling loads. Table XXIII, compiled by Frank Richards, managing editor of Compressed Air Magazine, requires no explanation. He estimates as the basis of the table that compressed air can be furnished for industrial purposes at 100 lbs. pressure at a cost of 5 cts. per 1,000 cu. ft. of free air. It appears from this table that a hoist with a cylinder 6 in. diameter, with a piston rod 1 in. diameter and a lift of 4 ft., using air at 90 lb. pressure and allowing 30% additional to cover all contingencies, including the taking up of the slack of the hoisting chain, will lift more than a ton to a

height of 4 ft. at a cost of $0.00035. A hundred of such lifts will thus be made, of course, for $0.035.

Molding Machines. The molding machine now holds a prominent and most important position among labor saving devices in the foundry, increasing the output and improving the grade of the products.

The degree of efficiency and the speed of operation depend upon the selection of the proper machine, and then upon the personality of the operator. Molding machines are so designed as to be operated with air at a pressure of 60 to 80 lbs.

The Sand Rammer. The sand rammer seems to come next in the order of consideration among the pneumatic tools of the foundry. Due to the marked improvements that have been made in the construction of this device, which tend to lessen the shock on the operator, and the education of the operators in the proper way to handle them, it has made a permanent place for itself, even against strong opposition, on the grounds of economy, lower production cost, larger output and improved quality of product which follow its use, and the adoption has become more general.

The pneumatic rammer does much more than merely to supply the power for the work. It also changes the character of the ramming and gives the operator a variety of execution in the ramming which his muscles, at the best, could not command. The force, the direction, and especially the rapidity of the blows are so completely under the control of the operator that we might compare the manipulation of the rammer to the playing of a musical instrument. It relieves the molder of the most fatiguing detail of his work.

The pneumatic bench rammer is a very handy tool as an auxiliary to the larger rammer. This rammer is very satisfactory for ramming a shelving pattern where the construction is such that it is difficult to ram under it with the larger tool. The bench rammer has been found practically indispensable for work of this nature.

TIME IN PEINING AND RAMMING

Size of cope	Hand	Sand rammer	Time saved, per cent.
12 ft. by 18 ins. by 4 ins.	5 min.	1 min.	80
12 ft. by 18 ins. by 10 ins.	10 "	1½ "	85
6 ft. by 6 ft. by 6 ins.	20 "	3 "	85
6 ft. by 6 ft. by 8 ins.	35 "	8 "	77
8 ft. by 6 ins. by 6 ins.	1 hr.	10 "	83
7 ft. by 3 ft. by 12 ins.	1 " 30 min.	16 "	82
15 ft. by 30 ins. by 16 ins.	2 hrs.	27 "	77
12 ft. by 7 ft. by 16 ins.	2 " 12 min.	34 "	74
87 ins. by 159 ins. by 10 ins.	4 "	40 "	83
19 ft. by 90 ins. by 15 ins.	8 "	1 hr. 30 min.	81

Pneumatic Hammers, Drills, Etc. The value of the pneumatic chipping hammer in a foundry, as a saver of time and labor, is so universally conceded that the time has passed when it is deemed necessary to submit comparative figures, especially as much depends upon the conditions of operation and efficiency of the air

plant. Suffice it to say that for all classes of chipping in foundry work, such as chipping fins off castings, cutting gates, risers, buttons off anchors, and general trimming, one man with one hammer of the proper size will do as much work as three or four men chipping by hand. These tools are made in different sizes, with piston strokes of 1 to 5 ins., to meet different conditions. It is important that the proper size tool should be selected for the work, to insure the best results, the short stroke tools begin intended for the lighter work, requiring a light and very rapid blow, the longer stroke tools for the heavier work, requiring a heavy and slower blow. The medium sizes, with 2 and 3-in. piston stroke, are the sizes most generally used for foundry work.

The rotating air drill is another very familiar labor-saving device, though its field of usefulness in a foundry is somewhat limited. It is more particularly a general shop tool, possessing a very wide range for drilling, reaming, tapping, flue rolling, running in stay bolts, studs, and other applications seemingly limitless. It has established itself next to the pneumatic hammer as a most generally used air tool.

Like the other pneumatic devices for foundry use the sand sifter also proves to be a time and labor and cost saver. The saving effected has been figured out as follows:

Including the cost of air, based on an efficient compressor installation, and figuring generally at 3 cts. per hr. for maintenance of sifter, compressor, pipe line, hose couplings, etc., and also including labor at 15 cts. per hr., the cost would be 27 cts. per hr. When you consider that one man with one machine will screen in one hour as much sand as a man would riddle by hand in one day, and basing his time at $1.50 per day, you will see that you effect by the use of the machine a saving of $1.23 in one hr.

The air torch has been found a great time and labor saver, being used for skin-drying copes, molds, etc., for heating ladles, lighting cupolas and in casting repairing processes.

The air nozzle for blowing blacking on molds, cores, etc., is also a universal favorite. This device is in the shape of a T, made of about ½ in. pipe with the discharge end bushed to about ¼ in. The air is connected so as to cross the top of the T. A short section of hose which goes to the receptacle holding the blacking is connected to the stem of the T, and as the air is blown through the top of the T it siphons the blacking and blows it in a spray over the work, reaching and covering every corner and crevice.

Cleaning Castings — The Sand Blast. There is hardly any operation of the foundry of greater importance, and which contributes more to a satisfactory factory product, than the proper and thorough cleaning of castings. It has been an operation requiring time and patience, and involving heavy expense. The cleaning of castings is a subject that has been given unusual attention, being followed by experiments with various and sundry methods and devices for the successful and economical accomplishment of the desired results, including brushing, tumbling, pickling, blowing, etc. These

methods have each shown marked advantages as applied to particular classes of work, but as a commercial proposition for all classes of castings, large, medium and small, steel, iron, aluminum and brass, the solution has been found in the sand blast, and here again, compressed air plays a most important part and shows its superiority over other actuating powers for general foundry work.

There are many makes, styles and kinds of sand blast apparatus on the market, and superior points are claimed by the manufacturers for each, some advocating the use of air under high pressure, and others under low pressure. The proper air pressure for sand blasting as applied to particular classes of work, has been the subject of much discussion among foundrymen and also sand blast manufacturers, and numerous theories have been expressed through the trade journals. There have also been a number of tests conducted on different classes of work, with varying air pressures, and the consensus of opinion as expressed in the reports of these various tests, at least so many of them as it has been the writer's privilege to read, seems to favor the high pressure blast for all classes of work. It is conceded that the volume of air required is governed by the size of the opening in the sand blast nozzle, and the pressure maintained, based on the standard flow of air at a given pressure through a given size orifice. Therefore, the higher the pressure, the greater the volume of air used, but the amount and quality of work done increases correspondingly without added labor costs. It has been proven in these tests that twice as much work can be done at 50 lbs. pressure as at 20 lbs., at 64 lbs. as at 30 lbs., and at 72 lbs. as at 40 lbs. It has also been shown that for gray iron and malleable castings they can be cleaned best and quickest with an air pressure of 80 lbs. — brass and aluminum castings at not lower than 60 lbs., while for steel castings, the hardest to clean, not less than 90 lbs. The character of the material and its ability to withstand the impact of the sand will determine the pressure adaptable.

As a result of a very thorough test of the economy of sand blast cleaning, conducted by one of our leading technical schools, in collaboration with one of our largest steel foundries, I am able to give in tabulated form data showing that the total cost per ton for cleaning castings, with a modern high pressure sand blast, is less than $0.80. This is figured on a basis of an equipment valued at $4,000 and including interest at 6%, and depreciation 10%; also power for exhaust system.

Air pressure generated	97.5
Air pressure at blast, lbs.	80
H.p. for air	53
Interest and depreciation	$.0307
Maintenance, air	$.105
Maintenance, sand	$.279
Power for exhaust fan	.0577
Nozzle	.0104
Total	.4828
Labor	.316
Total	.7988

Compressed Air in General Machinery Work. The reader is referred to Compressed Air for the Metal Worker, by C. A. Hirschberg, published by the McGraw-Hill Book Co. of New York, N. Y., for a very detailed discussion of this subject.

Pneumatic Tool Costs in Shipbuilding. (Chas. Schofield in Compressed Air, Nov., 1906.) It was some time before the men using pneumatic tools could be prevailed up to admit that there was sufficient benefit derived from their use to warrant a reduction from the hand piece-work rate, and it was only by diplomacy that a reduction of 40% on all chipping and cutting was achieved. At this time, the men experienced great difficulty in chipping a plate edge to a bevel, or when dressing a shell butt, on account of the hammers having round bushings to take the shank of the chisel, whereby the man operating the tool had to twist the chisel as best he could without any resistance from the hammer. But all the up-to-date hammers of to-day have hexagon bushings, and the chisels have hexagon shanks to suit, so that the operator can twist the chisel to any desired angle by twisting the hammer, while a calking iron with a round shank can be used in the same manner without the bushing being changed. The current piece-work rate for pneumatic chipping solid cutting and calking in the United States is about 50% less than the piece-work hand rates of Great Britain; that is, taking the day-work rates of both countries as a basis. Another feature of the pneumatic calking hammer is that it calks the toe of the gunwale, waterway, tank margin and bulkhead bounding bars without their having been either planed or chipped. This allows the builder to order the said angles the same size as he would if they were not to be calked.

Pneumatic hammers are used extensively by engineers for dressing propeller blades, the palms of structs for vessels with twin screws, bed plates, cutting key ways, cleaning castings, etc., in fact, there is very little hand chipping done in the fitting shops of the American engine builders.

Pneumatic Drills. When pneumatic drills were first introduced to shipbuilders they had to compete with electric drills of all sizes and weights; and during a four weeks' test at the works of William Cramp & Sons, of Philadelphia, the pneumatic drills proved their superiority. At the time of the test we were building three cruisers and two battleships, which had protective decks made up of two plates, each 1½ ins. thick, connected by 1¼-in. rivets. It was on these plates we made the test, the average for the twenty-four days being as follows:

	Holes drilled	
Air pressure	Pneumatic	Electric
On 12 days, being 90 lbs.	248	100
On 9 days, being 84 lbs.	232	100
On 3 days, being 76 lbs.	208	100

The result was that we dispensed with twenty-six electric drills, and took 60% off the piece-work rate of drilling on this class of work; we also made a reduction of 60% on the price of holes drilled

in the deck plating for deck planking, and took 50% off all other drilling on the ship, except odd work.

Pneumatic drills are now used for every conceivable purpose by American shipbuilders, among others, cutting out side-light holes, ventilator and coal port-holes in the deck, boring stern-post gudgeons, wood backing for armor-plate bolts, tube cutting, tube expanding, tapping for stay bolts, screwing in stay bolts, and by using a speed reducing gear attached to the drill it is possible to tap up to 4 ins. diameter, and to operate this combined machine only one man and a boy are required. In fact, the pneumatic drill is an indispensable factor in connection with speedy and economical ship construction in its various branches.

There was in use at that time, a stationary riveter of the ordinary type, driving rivets in such portions of the ship as could be assembled and handled as a whole, namely, frames, water-tight doors, etc., such as are usual in ordinary merchant vessels. A very short experience with compression riveters showed that their great weight — reaching over 2,500 lbs. for a 6-ft. gap — interfered too much with the facility of handling to make them either useful or economical.

We then turned our attention to the pneumatic hammer, which delivers an almost continuous series of blows against the end of the chisel, calking tool, or rivet die. The hammer is light, powerful, short enough to go in between frame spacings, and small enough in diameter to get at rivets in corner angles. For rivets up to ¾ in. diameter it can be held in the hand, but for rivets of a larger diameter the hammer should be held in a device suitable to the location of the work on the vessel, for instance, shell device and deck device. It is, however, almost impossible to hold on to the rivet by hand unless a spring dolly bar is used instead of the heavy holding-on hammer used in hand riveting, the heavy holding-on hammer being fairly jarred off the head of the rivet by the rapidity of the blows from the pneumatic hammer, giving the holder-on no opportunity to bring his tool back into position between blows as in hand riveting.

Portable Pneumatic Yoke Riveter Complete. In connection with the above-mentioned pneumatic hammer there is used a simple pneumatic hold-on consisting only of a cylinder carrying a piston, behind which air is admitted, the rod extending through the front head and being cupped out to go over the head of the rivet.

Combining these two machines with a yoke, the hammer being mounted on one arm and the holder-on on the other, makes a self-contained machine in which the yoke can be made very light, as it has to resist only the pressure of the air against the end of the holder-on cylinder, and the reaction of the hammer blows. Various sizes of these yoke riveters are used for riveting the center keelsons, longitudinals, side keelsons, etc. They are also extensively used for riveting certain parts of turrets, gun-carriages, etc., where first-class riveting is absolutely necessary.

For driving rivets in frames and brackets, intercostals and beam knees, etc., we use a jam riveter and pneumatic holder-on.

The above descriptions give the methods for driving all rivets that can be reached on both sides by a yoke or jam riveter. There remain three classes of rivets in a ship, as follows: (1) Those through decks and tank tops, mostly countersunk, and all driven downward from above; (2) bulkhead rivets, nearly all with full heads; (3) those in the outside of the vessel and all countersunk. These three classes must be reached by riveters on one side and holders-on on the other, without any connection whatever between them. The first class are most easily driven, and for them the hammer is attached to a universal swivel head, mounted on a pipe or T-bar. The operator raises the hammer to bring the flat die on to the rivet, and the pipe or T-bar being secured at the center, holds the hammer in position while the rivet is being driven. A second man, with a pneumatic chipping hammer cuts off the surplus metal, and the riveting hammer being brought back on the rivet, a few seconds complete the operation. In this case the pneumatic holder-on is operated from below by a third man, being braced against the bottom of the ship or the next deck below.

For the second class, the hammer is simply held in the hands of the operator, said hammer having about a 4½-in. piston stroke, and as the die is cupped out to form the snap point, there is no tendency to slip off the point. The holding-on is done by a spring dolly bar, which I will explain later.

We now come to the third class, or shell rivets, which, in many respects, are the most important rivets in the ship, requiring the most careful workmanship and the best finish. Therefore it is a serious mistake for shipbuilders to attempt to drive shell rivets by pneumatic power until they have established pneumatic riveting on all inside work, because the men operating the tools should be accustomed to handling the hammers before being put on this important part of the work. It is evident at the start that the varying thickness of plates, frame flanges and liners, and especially the depths of countersink render it impracticable to so gauge the length of rivet used that there will always be just enough metal to properly fill the countersink and finish the point, and that, therefore, as in hand riveting, a longer rivet must be used. After the point is beaten down and the surplus metal crowded off to one side, this surplus must be chipped off, and the point be finished up, rounded slightly, and any seams between the rivet and the plate driven together and closed. To do this a certain amount of freedom of motion must be allowed in the hammer, so that its axis may be inclined at a slight angle in any direction with the axis of the rivet itself.

This result is attained by mounting a pneumatic hammer in a device having a universal movement attached to the end of a T-bar, instead of its being immovably fastened to it. For bottom riveting there is a flat bar adapted so as to be mounted on the shell of a ship in any desired position. This bar carries an adjustable support, connected by means of a swivel joint, with a holder in which is mounted an adjustable frame bar, pivotally sup-

porting at one end a pneumatic hammer, and at the other an adjustable distance piece.

At one setting a space of 14 ft. to 16 ft. sq. can be reached with the above device, and when it is necessary to move the device to another position the change can be effected in about ten minutes. A spring dolly bar is used for holding-on, thus dispensing with the costly method of a wood backing, necessary when a pneumatic holder-on was used, as was the case a few years ago, and an ordinary pneumatic chipping hammer is used to cut off the surplus metal before finally finishing. It is evident that the freedom of movement of the hammer can be secured in other ways, such as a ball and socket joint of large radius, but we have found the above device more satisfactory and all that can be desired.

TABLE XXIV. COST OF PNEUMATIC RIVETING FOR SHIP CONSTRUCTION

Distribution	No. of rivets	Diameter of rivets, in.	Machine rate each, cts.	Hand rate each, cts.
Keel (flat)	6,217	1	2½	4½
Shell	21,628	⅞	1¾	3½
Shell margin (bilge single line)	1,122	⅞	3	4½
Longitudinals, open	24,632	¾	1¼	2¾
C. V. K. brackets	3,197	¾	1	3½
" "	....	..	1¼	3½
" "	....	..	1½	3½
Longitudinals under tank	664	¾	1¾	2¾
Longitudinals, bars	2,989	¾	1¼	2¾
Tank top stiffeners	1,129	¾	2½	3½
Tank top margin	4,033	¾	1½	2¾
Tank top rider	3,209	¾	1¼	2¾
Tank top lugs	1,520	¾	1¾	3½
Tank top	4,467	¾	1¼	2¾
C. V. K. cross vertical keelson	12,723	¾	1	3
Hold stringer	1,184	¾	1½	3
Floors	123	¾	1¼	3
Floors (odd)	5	¾	2	6
C. V. K. (odd)	38	¾	2	6
Bulkheads	1,318	¾	1¼	5
"	3,051	¾	1¼	3¼
"	231	⅝	1½	2½
Total	93,480			

	Holes drilled Pneumatic	Holes drilled Electric
Air pressure on 12 days, being 90 lbs.	248	100
Air pressure on 9 days, being 84 lbs.	232	100
Air pressure on 3 days, being 76 lbs.	208	100

For riveting the side shell plating the same device is used, with one exception, and this is as follows: there is a holder provided with a T-shaped slot, the sides of which form a bearing for the T-shaped frame bar, while allowing said bar to be moved from one position to another in said slot; and a friction spring and set screw, respectively adapted to bear against the bottom of said frame bar when the latter is in position in said slot and to lock the frame bar in any desired position in said holder.

The spring dolly bar now used is made of a piece of 3-in. pipe about 12 ins. long, having at one end an ordinary cast-steel handle, while at the other there is a bushing, through which a set screw holds the cup or snap. Inside the pipe is a piece of round iron, about 6 ins. long, backed up by a spiral spring.

The quality of the work done by all these machines, both inside and outside the shell, is first-class in every respect, and far superior to hand work, seeing that a rivet driven by a pneumatic hammer has to be about 12% longer than a rivet driven by hand, which goes to prove that the hole is better filled when the work is done by pneumatic tools, and such is the unanimous opinion of the inspectors who have been and are on duty in the American shipyards.

That this is natural appears from several considerations. The rivets are closed down more rapidly and at a much higher temperature, and, as it is always easy to bring the axis of the hammer in line with the axis of the rivet, and, in fact, natural for the men to do so, the rivet is plugged at once by the first blows of the hammer, thoroughly filling the hole throughout before the point begins to form. The tendency of hand riveters to save labor, to form the point without thorough plugging, leaving a rivet which, though looking all right and passing the tester, is liable to loosen afterwards in service from the constant jar and vibration of the hull, is, therefore, avoided. In many confined places, also, where only one man can strike, and the space for the swing of the hammer is confined to the frame spacing or less, hand rivets are very apt to be poorly driven, but it is evident that such considerations do not affect the machine, and that, if the pneumatic hammer can get to the rivet at all, it is as well put in as in the most open parts of the work.

As to the cost of pneumatic riveting, I submit the figures of Table XXIV, which are piece work rates current in the States, also figures comparing them with the British piece-work hand rates. In making this comparison, I must call your attention to the fact that both day-work and piece-work rates in America are about 35% higher than in Great Britain. This is due chiefly to the cost of living being higher. So that the piece-work prices for pneumatic riveting in Great Britain should be one-third less than the prices paid in America.

Table XXIV was compiled from an actual test covering a period of 3 weeks at the Chicago plant of the American Shipbuilding Company.

Total cost of job by hand would have been......	$2,986.87
Total cost of job by machine was..............	1,403.31
Saving of machine over hand work............	$1,583.56
Average cost per rivet of hand work...........	3.19 cts.
Average cost per rivet of machine work.........	1.50 "
Average saving per rivet of machine hand work	1.69 "

Average cost of machine riveting was 47% of hand cost.

The amount that should be added to machine cost to cover interest, maintenance of plant, and operation of compressor, is about 15% of the gross earnings of the tools.

It is only fair to mention that, at the time the above test took place, about 7 years ago, pneumatic tools were not so perfect as they are to-day, and their application to ship construction has been very much simplified. For instance, when driving bulkheads and shell it was customary to use a pneumatic holder-on, which necessitated something to act as a backing for the tool, said backing having to be built up, which added considerably to the total cost of riveting, whereas now a spring dolly bar is used, which the holder-on holds in his hands; again, the shell device for holding the riveting hammer while driving the rivet has been very considerably improved, and can be removed from one position to another on the ship in less than one-fifth the time required to remove the old device.

TABLE XXV. BRITISH COSTS OF PNEUMATIC RIVETING

Distribution	No. of rivets	British pneumatic Price per 100 s. d.	British pneumatic Total cost £ s. d.	British hand Piece-work s. d.	British hand Total cost £ s. d.
Keel (flat)	6,217	7 0	21 15 2	11 10	36 15 8
Shell	21,628	5 0	54 1 5	8 8	93 14 5
Tank margin	1,122	8 4	4 13 6	10 0	5 12 2
Longitudinals, open	24,632	3 6	43 2 1	8 6	104 13 9
C. V. K. brackets	3,197	3 6	5 11 10	8 6	13 11 9
Longitudinals under tank	644	5 0	1 13 2	9 6	3 3 1
Longitudinals, bars	2,989	3 6	5 4 7	9 6	14 3 11
Tank top stiffeners	1,129	7 0	3 19 0	10 0	5 12 11
Tank top margin	4,033	4 2	8 8 0	10 6	21 3 6
Tank top lugs	1,520	5 0	3 16 0	10 0	7 12 0
Tank top rider	3,209	3 6	5 12 4	10 6	16 16 11
Tank top	4,467	3 6	7 16 4	10 6	23 8 0
C.V.K. vertical keelson	12,723	2 10	18 0 6	8 6	54 1 5
Hold stringer	1,184	4 2	2 9 4	8 6	5 0 8
Floors	123	3 6	0 4 4	8 6	0 10 5
Floors (odd)	5	5 9	0 0 4	11 6	0 0 7
C. V. K. (odd)	38	5 9	0 2 2	11 6	0 4 4
Bulkheads	3,051	4 2	6 7 1	7 0	10 13 7
			£192 17 2		£416 19 1
					192 17 2
Amount saved by machine over hand (British rates)					£224 1 11

Pneumatic Log Sawing Machine. A pneumatic log sawing machine consists of a saw and frame weighing 85 lbs. and an engine of brass tubing weighing 65 lbs. The frame is manufactured in 2 sizes to cut in 16 and 24-in. lengths.

The capacity of the saw in logs is given as 500 per 10-hr. day or 20 cords of 4-ft. wood.

The ordinary working pressure required is 75 lbs., the free air consumption at 65 strokes, per min., being 33 cu. ft.

Air Consumption of Pumps. Andre Formis, June 14, 1913, in

Engineering and Mining Journal, describes the use of a recording air meter for taking time studies of rock drills on air lines.

The air meter was also used to investigate the air consumption of a small, single-stroke 7 by 3½ by 7-in. plunger pump. The water was pumped a height of 250 ft. on an angle of 33 degs., the size of the suction and discharge lines being according to the manufacturers' specifications. The strokes per min. were counted and noted on the chart at the corresponding air-flow line. It was found that at 130 strokes, 85 cu. ft. were used. The h.p. drawn from the boilers to compress this amount of air was 13.1 h.p., according to the manufacturer's catalog. The theoretical power required to pump the amount of water is 2.56 h.p., without friction or leakage losses. The electrical power required to pump this amount would be conservatively four boiler h.p.

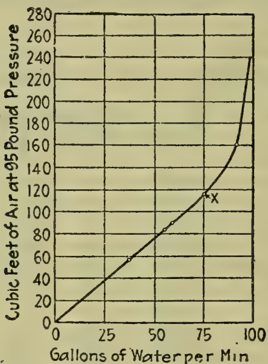


Fig. 7. Pump performance as given by air meter.

Fig. 7 has been plotted from a set of observations. It shows that the most economical speed is about 75 gals. per min., corresponding to the point marked *X*. This happens to be about three times the water to be handled per day; thus it determines the size of the sump, and the number of attendants required to run a given number of pumps. Of course, the economical point is determined by such considerations as leakage in air valve, slippage in water end and water valves, moisture in compressed air inducing freezing, and size of suction and discharge pipes. This confirms the well known fact that pumping by air is uneconomical. At times electric pumping would entail considerable expense, but for permanent installations any reasonable additional cost will be repaid in a short time.

English Costs on Scaling Boilers. With regard to scaling boilers by pneumatic hammers, Messrs. John Allen and Sons, of Kilburn (England) give the following comparative figures in the Engineer for 1907, one boiler — Cornish, 30 ft. by 6 ft.— only being

referred to, the average thickness of scale being ⅜ in. The two pneumatic hammers weighed 9¾ lbs. each, with pistons 1⅟16-in. diameter, and 1¾-in. stroke. When the work was done by hand 8 men at 18 cts. per hour were employed for 9 hrs. per day, each man receiving $2.25 per day extra as "dirt" money. The job took 6 days.

	£ s. d.	Cost per day
8 men at $2.25	3 14 0	$18
Total cost for the 6 days......	22 4 0	108

With 2 pneumatic hammers, 4 men employed, 2 using the pneumatic hammers and 2 their hand tools, the same job took but 3 days.

	£ s. d.	Cost per day
4 men at $2.25	1 17 0	$8.99
Cost for the 3 days	5 11 0	26.97
The saving in labor thus being.	16 13 0	80.81

Taking the above figures to be correct, it is seen that the two pneumatic hammers did no less than seven-eighths of the work, and that they could have done the whole of it in a trifle less than 3½ days, for which time the cost of labor would have been $15.73 only, and the saving $92.16.

The riveting hammers are now capable of closing rivets up to 1½-in. diameter, and are employed in all kinds of constructional ironwork, both in the yards and in the field; on boiler work, on furnaces, combustion chamber, and shell plating, and in shipbuilding for both shell, bulkhead, and deck riveting.

Hydro-Compressor Installation Costs. The following from Design and Construction of Hydraulic Plants, by R. C. Beardsley, quotes Professor Unwin as stating that it is practical to transmit power by compressed air to a distance of 20 miles with a loss of 12%.

The cost of a hydro-compressor installation is less than a turbine plant, as there are no journals, shafting, gearing, etc., the only cost being for the boiler iron and excavation. The cost of excavation will of course vary with the condition. Rock excavation will cost $5 to $8 per cu. yd. and earth from 50 cts. to $3.

Mr. Weber places the cost of a 5,000 h.p. compressor at $42,000. The boiler iron ought not to cost more than 4 cts. per lb. erected. Of course the same dam, head gates, canals and racks are required as for a turbine plant, but no power house.

For distances less than 5 or 6 miles (and no doubt the future will see this increased), the transmission of the power by means of compressed air is as efficient as by any other means, a 2% loss being usually allowed. A velocity of 60 ft. per sec. may be allowed in the pipes, and as each h.p. at 85 lbs. pressure takes about 14.4 cu. ft. of air per min., the area of the pipe may be determined. Weber gives the cost of a 20-in. steel pipe 4 miles long carrying 5,000 h.p. at 85 lbs. pressure as $3.05 per ft. laid, making the cost per mile $18,500, and for 4 miles $74,000. An electric transmission would cost as follows:

2 governors (for 2 units)	$2,000
Generator house	5,000
Switch board	2,000
4 miles transmission line	4,500
Step up and step down transformers	30,000
Generators and exciters	50,000
	$93,500

The cost is more in favor of the hydro-compressor plant, as the distance grows less, and vice versa.

Victoria Mines Hydro-Compressor Plant. The following article describing an application of Mr. Frizell's method for the compression of air by the direct action of falling water is taken from Engineering News.

The hydraulic compressed air plant of the Victoria Mines is located in Ontonagon County, near Rockland, Mich. Water is taken from the Ontonagon River and after passing through the compressor is returned to the river a mile further down stream. A concrete dam 300 ft. long and 10 ft. high was built across the river 4,000 ft. up-stream from the compressor house, and a canal with a sectional area of 350 sq. ft. conducts the water from the dam to the compressors. At the foot of the canal three vertical circular and smoothly cemented shafts, each 5 ft. in diameter, were sunk to the depth of 330 ft. These shafts terminate in a chamber 57 ft. wide, 22 ft. high and 50 ft. long. The chamber then narrows to a width of 18 ft. and a height to the center of the arched roof, of 25 ft. This part of the chamber is 232 ft. long, making a total length of 282 ft. Here the chamber is reduced to a tunnel 10 ft. high, and after a run of 40 ft., it ascends on an incline to the surface.

At the bottom of the shafts are fitted steel tubes, which extend into the chamber 16 ft. These tubes flare from a diameter of 5 ft. at their connection with the shafts, to 7 ft. 4 ins. at their base, while immediately below each of them is placed a concrete spreading pier. Steel tubes are also fitted to the upper ends of the shafts and extend 6 ft. above the base of the forebay. Into these are telescoped other pipes, to which are attached the head pieces of the compressors.

By this arrangement the flow of water through the compressors is controlled, the head piece being lowered below the water level of the forebay, when the compressor is working, or raised above the water line, so that no water can pass through it, when the compressor is shut down.

The air capacity of the underground chamber, between the water line and the roof, is 80,264 cu. ft. Out of the top of this chamber extends a 24-in. air main, while alongside of it runs a 12-in. blow-off pipe. This latter pipe has its lower end on a level with the water line of the chamber, which is at such a height as to keep the down-take tubes of the compressors always sealed with water. The office of this blow-off pipe is to prevent the air pressure becoming so great as to force the water away from the down-take tubes, thereby breaking the water seal and allowing the air to

escape through them. When the air pressure becomes sufficient to force the water to the level of this blow-off line, air and water escape from the blow-off pipe until the pressure is relieved and the end of the blow-off pipe becomes again sealed by the water. The air and the blow-off pipes are both cemented air-tight into a 30-deg. tunnel, which carries them to the surface, where the blow-off terminates and the air main is continued to the mines. It may be remarked that when the blow-off is in operation it throws a mixed stream of air and water some 500 ft. into the air.

The headpiece referred to above consists of an annular pipe or header attached to the adjustable telescoping pipe. This header, which is about 10 ins. in diameter, is connected with eight 7-in. vertical intake air pipes, the upper ends of which always project above the water level of the forebay. The headpiece is supported by I-beams of the compressor house. The headpiece and concave adjusting cone can be raised and lowered by lifting screw and capstan nuts. The convex casting of the adjustable head is riveted to a larger diameter tube, thereby making each headpiece an inverted tank, or float.

The compressor is set in operation by lowering the headpiece by turning the capstan nut until the lower rim of the convex casting settles a few inches below the surface of the water in the forebay. In this position the water rushes over the ⅝-in. air tubes and passes down between the conoid castings into the vertical shaft. On passing the ends of the small air tubes the water drops away at an increased velocity, thereby creating a partial vacuum, which causes air from above to rush in. This air is taken up by the water, in the form of small bubbles, and carried down the shaft, being gradually compressed thereby. On reaching the bottom of the shaft the mixed volume of water and air is spread out in all directions by the conical cement pier. The water then slowly flows along the air chamber, while the air rises through it and accumulates in the dome of the chamber. On reaching the end of the chamber the water is free of air and flows up the inclined shaft and discharges into the tail race.

Automatic regulation of the flow of water over the small air tubes is obtained by means of a small air pipe, which runs from the air chamber up to and connects with the adjustable headpiece. The end of this pipe in the chamber is placed at such a height that, when the air pressure reaches the desired point, the pressure will raise the adjustable head and stop the flow of water over the air tubes. As soon as the air pressure in the chamber is relieved, the headpiece is lowered and the compressor placed in operation again.

As noted above, three vertical shafts are used instead of one larger one. This arrangement was decided on for the reason that a higher efficiency could be obtained during a dry season, with less water, and also that thereby a very high efficiency could be secured through a range of 1,000 to 5,000 h.p. According to tests which were made by Messrs. Sperr and Hood, of the Michigan School of Mines, the efficiency of the plant, when running at about

maximum capacity, is 82%. The total distance between water level of the forebay and the water level of the air chamber is 342 ft., while the distance between forebay water level and tail race level is 71 ft. This gives an air pressure head of 271 ft., which produces a pressure of 117 lbs. per sq. in. in the air chamber. The plant was designed and built by Mr. C. H. Taylor, of Montreal, and cost less than $22 per h.p., while the dam and canal cost about the same. The cost of operating the plant averages about $2.25 per h.p. per year, allowing 5% interest on first cost.

Cost of Compressing by Water and Electric Driven Compressors and the Direct Action of Water. (Compressed Air Magazine, Nov. 1908.) An hydraulic air compressor installed at Clausthal in

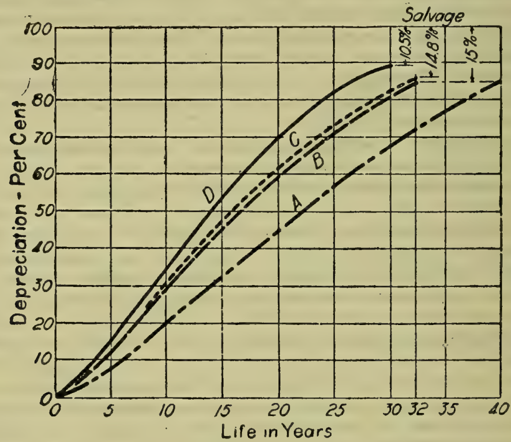


Fig. 8. Depreciation of marine equipment.
A — Steel steam vessels on great lakes.
B — Steel steam vessels on tidewater.
C — Steel barges, floats, etc., on tidewater.
D — Wood tugs, barges, etc., on tidewater.

1907. Water is led to the air suction pipe of cast iron 218 mm. in diameter and 150 m. long, which is laid down an inclined shaft discharging into the bottom of a receiver 1.1 m. in diameter and 4.5 m. high, which rests on an I-beam support in the shaft 52 m. below the overflow tunnel. On the receiver is a pressure gauge and a pipe that passes up parallel to the discharge, entering it at the discharge level.

The compressed air escapes through a valve passing into the reservoir and then through an 80 mm. pipe to the mine. The overflow water passes up through a 218 mm. pipe 50 m. long.

The average flow of water through the system was 3 cu. m. per min., falling 99$\frac{3}{10}$ m. between the intake and discharge levels

yielded 10 cu. m. of air per min. at 90 lbs. per sq. in. The work performed was 54 h.p., and the theoretical power of the water was 70.5 h.p., with an efficiency of 77%.

The turbine wheel installed had an efficiency of about 75% and the compressor an efficiency of 85%, the combined efficiency being 64%.

CHAPTER XVI

GAS PLANTS

Cost of Trenching and Pipe Laying. The reader is referred to Gillette's Handbook of Cost Data for detailed costs of trenching, paving and pipe laying.

Percentage of Gas Manufactured on Which There is No Return. We have derived the following figures from the 1914 Report of the Gas and Electric Light Commission of the Commonwealth of Massachusetts. There were 59 companies reporting which manufactured a total of 13,234,929,044 cu. ft. of gas. Of this amount 758,097,294 cu. ft. or 5.73% was unaccounted for and 81,633,744 cu. ft. or 0.62% was used by the companies. This makes a total of 839,731,038 cu. ft. or 6.35% of the total gas manufactured, on which there was no return. That this amount can be materially lessened is shown by the fact that some of the companies report losses as low as 1% or less and further the same company seldom holds the unenviable record of showing a maximum for "gas unaccounted for" for two years in succession. The maximum of gas unaccounted for was 18.75% for the year ended June 30, 1914, and 21.47% for the year ended June 30, 1913.

Detailed Cost of a Gas Plant in a City of 90,000. The following is an abstract of an appraisal report by Henry L. Gray.

The gas manufactured by this company is distributed and sold in a western city of 85,000 population and in suburban towns of 5,000.

The average number of cu. ft. of gas manufactured daily during a year was 815,900, of which amount 666,600 cu. ft. were sold, and 149,300 cu. ft. remained unaccounted for, or a loss of 18.3 per cent.

The following table shows the number of consumers and services as well as the number of meters and other appliances in use.

December 31, 1911	Total
Number of services	11,762
Number of consumers	11,810
Number of meters	11,910
Number of arcs	3,575
Number of ranges	11,411
Number of gas plates	1,835
Number of water heaters	5,564
Number of room heaters	4,019
Number of gas engines	3
Number of miscellaneous appliances	2,199
Total mileage of mains	236

Manufacture of Coal Gas. Coal gas is primarily a mixture of a number of simple gases, the principal ones being hydrogen, marsh gas, carbon dioxide and carbon monoxide. Hydrocarbons are pres-

ent in certain forms, together with certain inert gases and impurities, which are later removed. It is produced by the destructive distillation of coal in air tight retorts or ovens, which are heated externally. The design of the generating apparatus differs considerably in various plants, but the principle remains the same in all. Approximately three hundred pounds of coal are charged into a retort, which is then sealed and heated by the combustion of coke for about four hours, in order to expel all of the gas from the coal. The retort is then opened, the coke withdrawn, to be later used for fuel, or in the manufacture of water gas; the retort is recharged and the process continued. Air is carefully excluded from the retorts, the gas being discharged under water; and this fact is responsible for the incomplete combustion. A ton of good gas coal will produce about 10,000 cu. ft. of gas, 1,400 lbs. of coke, 12 gals. of tar and a varying quantity of ammonia.

Manufacture of Water Gas. Water gas is largely a mechanical mixture of hydrogen and carbon monoxide, which is produced by the decomposition of steam brought in contact with incandescent coal or coke. It contains practically no impurities, with the exception of sulphureted hydrogen, which is later removed. As it comes from the generator this gas burns with a pale blue or colorless flame, on account of the absence of illuminants, or hydrocarbons, and the gas has no value as an illuminating gas except when used in burners of the Welsbach type, which contain a mantle that becomes incandescent through heat, and thus affords light. Consequently, in order to burn water gas in the ordinary burner, it must first be carburetted, or enriched, with hydrocarbons. This is accomplished by means of introduction of crude oil into the generator, which diffuses and becomes permanently fixed in the gas.

The production of water gas requires about thirty-five to forty-five pounds of coke, and about four or five gallons of oil for 1,000 cu. ft. of gas generated. The chief objection to water gas is the high percentage of carbon monoxide which it contains, carbon monoxide being a very deadly gas if inhaled. In ordinary use, however, there is little likelihood of an accident resulting from this source.

Manufacture of Oil Gas. Oil gas is produced in almost the same manner as is coal gas, crude oil being destructively distilled in retorts, instead of coal. The production of oil gas, however, is largely confined to western cities, where a suitable supply of coal is either not available, or is too expensive for use. Oil gas is similar in composition to coal gas, but in many cases contains impurities which are difficult to remove. Many California cities are supplied with oil gas, owing to the presence of large quantities of low grade fuel oil.

Capacity of Plant. The plant under consideration produces both coal and water gas. The apparatus for the production of the former consists of eleven benches of six retorts each. These benches are of the semi-regenerative type, and have a total capacity of 550,000 cu. ft. per day. The water gas generating apparatus consists of three sets of producers of the Lowe type, having a total rated daily capacity of 1,750,000 cu. ft. which is probably

considerably in excess of the actual capacity. Owing to the fact that it is impossible to run a gas plant to its full capacity for any great length of time, on account of the necessity of shutting down different parts for cleaning and repairs, it is probable that the maximum continuous output of this plant under existing conditions will not exceed 1,100,000 cu. ft. per day.

It is probable that the purifying apparatus in use by this plant is entirely too small to take care of the output; and by the installation of an additional condenser and scrubber to the 7 ft. water gas set, and by the reconstruction of the 9 ft., 6 in. water gas set, and with the completion of the additional storage holder now in course of construction, it may be possible to increase the total output to 1,400,000 cu. ft. per day.

Operation of Plants. The water gas is manufactured by passing steam over incandescent coke and is carburetted or enriched by gas oil having a density of 26 degs. Baume at 60 degs. F. The purification of the gas is accomplished by means of various tar extractors, condensers, scrubbers, washers and purifying boxes filled with iron oxide. The circulation of the gas through this purifying apparatus is produced by means of steam driven blowers and exhausters. After purification the coal gas is discharged directly into the present storage holder, having a capacity of 502,000 cu. ft. The water gas, however, is first discharged into a relief holder, having a capacity of 115,000 cu. ft., where it is allowed to cool somewhat before being pumped into the storage holder. Eventually, however, both gases reach the storage holder, and are mixed together before distribution, in the approximate ratio of 48 per cent. coal gas and 52 per cent. water gas.

Distribution. The gas is distributed throughout the city by means of two separate distribution systems, known as the high pressure and the low pressure systems. The gas distributed through the high pressure system is forced through the mains by Ingersoll-Rand compressors, and is used to supply the outlying districts. The high pressure system also acts as a booster for a large part of the low pressure system, in which the gas is presumed to circulate under the pressure produced by the weight of the holder. About 65% of the total production of gas is sent out from the plant through the high pressure mains, a large portion, however, eventually finding its way into the low pressure system in order to boost those sections of the latter system on which there is an unusually heavy demand.

By-products. Very little attention is given by the present company to the manufacture of by-products, the greater portion of the coke produced being used for fuel in the recuperators of the coal gas plant, and in the water gas apparatus, only about twenty-five per cent. of the total quantity of coke produced being sold. The coal tar is sold to a refiner just as it is produced, no attempt being made to reduce it at the plant. The ammonia still was dismantled some time ago on account of its inefficiency, and a new one is at the present time in process of construction. The company is completing a new holder, having a capacity of 1,000,000 cu. ft.

TABLE I. CONDENSED ESTIMATE OF REPRODUCTION COST

1.	General office buildings	$ 18,900
2.	Gas plant buildings	26,853
3.	Shops and miscellaneous buildings	17,225
4.	Benches	33,000
5.	Water gas apparatus	35,450
6.	Purifying apparatus	33,775
7.	Station meters	8,700
8.	Boilers	4,300
9.	Other plant machinery	23,130
10.	Miscellaneous plant apparatus	7,440
11.	Plant piping and fittings	13,228
12.	Holders	91,875
13.	Paving	413,983
14.	Distributing mains *	*681,184
15.	Services	180,239
16.	Governors and regulators	10,807
17.	House meters	166,024
18.	Arc lights	48,360
19.	Teams and vehicles	22,630
20.	Tools and implements	8,750
21.	Testing apparatus	4,254
22.	Furniture and fixtures	12,943
23.	Engineering, supervision and organization expense	186,305
24.	Interest during construction	102,468
25.	Contingencies	107,591
26.	Stores and working capital	80,000
27.	Brokers' fees	87,728
28.	Real estate	153,147
	Total cost as of Jan. 1st, 1912	$2,580,289

* This includes an item of $70,000 for a transmission main connecting two widely separated parts of the system.

The costs used in this appraisal are based on prices prevailing previous to the World War.

TABLE II. DETAILED ESTIMATED COST OF REPRODUCTION

1. GENERAL OFFICE BUILDINGS.	
Office buildings, one story, brick and terra cotta with composition roof, 92,000 cu. ft. at $0.20	$18,400
Brick vault, at office	500
	$18,900
2. GAS PLANT BUILDINGS.	
Boiler house, brick and corrugated iron, 25,168 cu. ft. at $0.05	$ 1,258
Water gas building for 6 ft. 6 ins. and 7 ft. water gas sets, brick with corrugated iron roof, 44,800 cu. ft. at $0.09	4,032
Purifier house, brick with corrugated iron roof, 65,158 cu. ft. at $0.10	6,516
Exhauster house, brick with corrugated iron roof, 20,832 cu. ft. at $0.08	1,667
Compressor house, frame with corrugated iron walls and roof, 35,400 cu. ft. at $0.06	2,124
Coal bunker, frame and corrugated iron, 75,200 cu. ft. at $0.04	3,008
Water gas building for 9 ft. 6 ins. water gas set, frame with corrugated iron walls and roof, 58,384 cu. ft. at $0.07	4,087
Retort house, frame with corrugated iron walls and roof, 82,110 cu. ft. at $0.03	2,463

Coke shed, frame with composition roof, 3,000 sq. ft. at $0.35	$ 1,050
Blower house, corrugated iron, 240 sq. ft. at $0.50	120
Oil pump house, corrugated iron, 170 sq. ft. at $0.50	85
Shed over ammonia storage tank and tar well, frame and corrugated iron, 626 sq. ft. at $0.50	313
Plant tool shed, corrugated iron, 260 sq. ft. at $0.50	130
	$26,853

3. SHOPS AND MISCELLANEOUS BUILDINGS.

Stable, frame, 52,605 cu. ft. at $0.05	$ 2,630
Meter shops, frame, 53,482 cu. ft. at $0.05	2,674
Fitting shop, two story frame, 25,685 cu. ft. at $0.05	1,284
Storeroom and blacksmith shop, two story and basement, frame with corrugated iron, 79,747 cu. ft. at $0.05	3,987
Warehouse, two story, frame and corrugated iron, 35,910 cu. ft. at $0.04	1,436
Works office, frame, 21,250 cu. ft. at $0.07	1,487
Retort tool house, frame and corrugated iron, 100 sq. ft. at $0.50	50
Garage, frame and corrugated iron, 1,464 sq. ft. at $0.35	512
Brick and tile shed, frame and corrugated iron, 1,200 sq. ft. at $0.20	240
Pipe rack, frame and corrugated iron, 640 sq. ft. at $0.50	320
Wagon shed, frame and corrugated iron, 1,060 sq. ft. at $0.50	530
Paint and oil house, frame and corrugated iron, 200 sq. ft. at $0.50	100
Pipe shed, corrugated iron roof, no sides, 800 sq. ft. at $0.25	200
Cement sidewalk, 6,770 sq. ft. at $0.11	745
Brick vault, works office	350
Tile vault, storeroom office	400
Fence, board, 6 ft. high, painted, 800 lin. ft. at $0.35	280
	$17,225

4. BENCHES.

11 coal gas benches, Parker-Russell "Sixes," half depth, complete in place, with foundations, stacks and hydraulic main, at $3,000	$33,000

5. WATER GAS APPARATUS.

Water gas set, West. Gas Cons. Co., 9 ft. 6 ins. by 9 ft. 6 ins. by 9 ft., consisting of:

1 generator 9 ft. 6 ins. by 15 ft.
1 carburettor 9 ft. 6 ins. by 21 ft.
1 superheater 9 ft. 0 ins. by 26 ft. 6 ins.
1 seal, cast iron, 7 ft. by 7 ft. by 24 ft., complete in place, with foundations, charging floor and connections $16,135

Water gas set, Gas Machinery Co., type, 7 ft. by 7 ft. by 7 ft., consisting of:

1 generator, 7 ft. by 14 ft.
1 carburettor 7 ft. by 14 ft.
1 superheater, 7 ft. by 24 ft.
1 seal, steel, 6 ft. by 4 ft., complete, in place, with foundations, charging floor and connections $9,275

Water gas set, West. Gas Const. Co., 6 ft. 6 ins. by 6 ft. 6 ins. by 6 ft., consisting of:

1 generator, 6 ft. 6 ins. by 16 ft.
1 carburettor, 6 ft. 6 ins. by 18 ft. 6 ins.

1 superheater, 6 ft. by 24 ft.	
1 seal, steel, 5 ft. by 3 ft. complete, in place, with foundations, charging floor and connections	$ 9,275
	$35,450

6. PURIFYING APPARATUS.

Purifier set, consisting of:	
4 purifier boxes, Floyd 16 ft. by 12 ft. by 8 ft., cast iron,	
1 center seal,	
1 traveling cover hoist, complete, in place, with fundations and connections	$11,475
2 purifier tanks, steel, 11 ft. 6 ins. by 21 ft., complete, in place, with foundations and connections, at $4,075	8,150
Scrubber, 5 ft. by 16 ft., complete, in place, with foundations and connections..................	375
Scrubber, 5 ft. by 20 ft., complete, in place, with foundations and connections	465
Scrubber, 6 ft. by 24 ft. complete in place, with foundations and connections	660
Scrubber, cast iron, 7 ft. by 7 ft. by 24 ft., complete, in place, with foundations and connections	2,640
Condenser-scrubber, 6 ft. 6 ins. by 29 ft. 6 ins. complete, in place, with foundations	800
Tubular condenser, 6 ft. by 16 ft., complete in place, with foundations and connections	850
Tubular condenser, 5 ft. by 21 ft. complete, in place, with foundations and connections	900
Tubular condenser, 6 ft. by 22 ft. complete, in place, with foundations and connections	1,145
Condenser, cast iron, 7 ft. by 7 ft. by 24 ft. complete, in place, with foundations and connections	2,465
Tar extractor, "P & A" #5, with 6 ft. 4 ins. by 5 ft. 6 ins. by 4 ft. wash box, complete, in place, with foundations and connections.............	1,900
Tar extractor, "P & A" #10, complete, in place, with foundations and connections	2,130
	$33,775

7. STATION METERS.

Station meter, "H & M," 9 ft. with Hinman drum, capacity 56,000 cu. ft. per hour, camplete, in place	$2,900
Station meter, "H & M," 8 ft., with Hinman drum, capacity 45.000 cu. ft. per hour, complete, in place	2,500
3 high pressure meters, Westinghouse, #300, capacity 40,000 cu. ft. per hour, complete, in place, at $850	2,550
High pressure meter, "Westinghouse," #100, capacity 1,000 cu. ft. per hour, not installed	450
High pressure meter, "Westinghouse," #50, capacity 8,500 cu. ft. per hour, complete, in place..	300
	$8,700
High pressure meter, "Westinghouse," #100, capacity 16,000 cu. ft. per hour, not installed....	450
High pressure meter, "Westinghouse," #50, capacity 8,500 cu. ft. per hour, complete, in place	300
	$8,700

8. BOILERS.

2 boilers, "Erie," 72 ins. by 18 ft., 125# pressure, complete, in place, with foundations, brick work, full front, all fittings and 48 ins. by 55 ft. steel stack	$4,000
Feed water heater, 150 h.p., complete in place....	300
	$4,300

9. OTHER PLANT MACHINERY.

2 compressors, Ingersoll-Rand (Imperial) class 10-1 12 ins. by 16 ins. by 16 ins., complete, in place, with foundations and connections, at $3,900	$7,800
Blower "Sturtevant" #7, extra heavy, not installed	260
Blower, "Sturtevant" #7 extra heavy, belt connected to 10 ins. by 12 ins. 45 h. p. Atlas engine, complete, in place, with foundations and connections	1,095
2 blowers, "Sturtevant," #6 extra heavy, direct connected to Kerr 24 ins.—120 h.p. horizontal turbines, complete, in place, with foundations and connections, at $2,060	4,120
Exhauster, "Roots" #7 direct connected to 9 ins. by 9 ins. "Wachs" engine, complete, in place, with foundations and connections	1,430
Exhauster, "Roots" #5 direct connected to 6½ ins. by 7 ft. "Oil City" engine, complete, in place, with foundations and connections	1,231
Exhauster, "Roots," #5 direct connected to 5½ ins. by 7 ins., "Safety" engine, complete, in place, with foundations and connections	1,235
Governor, "Connelly," automatic and balance, complete, in place, with foundations and connections	1,115
Outside packed plunger pump, "Worthington," 10 ins. by 6 ins. by 10 ins., complete, in place, with foot valve and intake pipe	320
Outside packed pump, "Worthington" 5¼ ins. by 3½ ins. by 5 ins., complete, in place	157
2 Duplex pumps, "Worthington," 4½ ins. by 2¾ ins. by 4 ins., complete, in place, at $65	130
Duplex pump, "Worthington," 7½ ins. by 5 ins. by 8 ins., complete, in place	140
Duplex, pump, "Buffalo" 7½ ins. by 5 ins. by 8 ins., complete, in place	162
3 Duplex pumps, "Gardner," 6 ins. by 4 ins. by 6 ins., complete, in place, at $105	315
Duplex pump, "Canton #5," 5 ins. by 2¾ ins. by 4½ ins., complete, in place	70
Deep well pump, "Marsh," 8 ins. by 24 ins. by 4½ ins., complete, in place, with 4½ ins. by 40 ins. artesian deep well brass cylinder	300
Centrifugal pump, "United Iron Works 4 ins," direct connected to G. R. 20 h.p., 220 volt, d.c. motor, complete, in place	375
2 oil heaters, Western Gas Construction Company, at $30	60
Oil heater, own make,	25
Oil filter, American #1	30
2 oil meters, National #1, at 40	80
Hydraulic elevator, "Craig-Ridgway," capacity one ton, complete, in place	1,060
Coal elevator and conveyor, "Jeffrey," with G. E. 20 h.p. 220 volt, d.c. motor, complete, in place	1,440
Ammonia plant, 10% complete	180
	$23,130

10. MISCELLANEOUS PLANT APPARATUS.

Patterns of miscellaneous fittings and apparatus	$2,000
Seal, concrete, 4 ft. by 4 ft. by 7 ft.	25
Seal, concrete, 3 ft. 9 ins. by 6 ft. by 6 ft. 6 ins.	43
Separator, concrete, 6 ft. by 6 ft. by 6 ft. 6 ins.	50
Separator, concrete, 7 ft. by 5 ft. by 6 ft.	95
Tar and ammonia separator, concrete, capacity 10,875 gals.	480
Tar well, concrete, capacity 5,475 gals.	165

Tar well, concrete, capacity 37,000 gals.	$880
Water reservoir, concrete, capacity 37,250 gals...	615
Ammonia storage tank, steel, capacity 13,535 gals., complete, in place, with foundations and connections	750
Tar tank, double deck, timber and galvanized iron, capacity 40,875 gals.	600
Water tank, on top of coal bunkers, 1,430 gals. capacity	100
Artesian well 6 ins., 154 lin. ft., at $3........	462
7 coal and coke cars, steel, one cu. yd. capacity, 24 in. gauge at $100	700
Tram track, 12# rail, 24 in. gauge, complete, in place, 465 lin. ft., at $1	465
	$7,440

11. PLANT PIPING AND FITTINGS.

Cast iron pipe, 16 ins., 560 lin. ft. at $3.60........	$2,016
Cast iron pipe, 12 ins., 880 lin. ft. at $2.50......	2,200
Flanged pipe, 12 ins., 84 lin. ft., at $2.75........	231
Cast iron pipe, 8 ins., 302 lin. ft., at $1.40........	423
Wrought iron pipe, 8 ins., 580 lin. ft., at $1.10.....	638
Blast pipe, 15 ins, 216 lin. ft., at $1.50........	324
Miscellaneous small pipe, 6 ins. and under with fittings	2,000
Fittings, 16 ins.	2,068
Fittings, 12 ins.	3,250
Fittings, 8 ins.	78
	$13,228

12. HOLDERS.

Gas holder, 3 lift, in steel tank, capacity 502,000 cu. ft., complete, in place, with foundations and connections	$45,000
Gas holder, single lift in concrete tank, capacity 115,000 cu. ft., complete, in place, with foundations and connections	24,000
Gas holder, single lift in brick and concrete tank, capacity 56,000 cu. ft., complete, in place, with foundations and connections (Used as oil storage tank)	11,200
Gas holder, 4 lift in steel tank, capacity 1,000,000 cu. ft. at Plant B. in course of construction, expenditure to date	11,675
	$91,875

13. PAVING.

Asphalt paving, torn up and relaid, 69,588 sq yds. at $4	$278,352
Brick paving, torn up and relaid, 18,088 sq. yds., at $3.50	63,308
Stone block paving, torn up and relaid, 14,030 sq. yds. at $3.50	63,308
Stone block paving, torn up and relaid, 14,030 sq. yds., at $4	56,120
Bitulithic paving, torn up and relaid, 2,301 sq. yds. at $4	9,204
Granitoid paving, torn up and relaid, 871 sq. yds. at $4	3,484
Wood block paving, torn up and relaid, 414 sq. yds. at $3.50	1,449
Plank paving, torn up and relaid, 3,444 sq. yds. at $0.60	2,066
	$413,983

14. DISTRIBUTING MAINS.

WROUGHT IRON SCREW PIPE

¾ in. 250 lin. ft. at $0.14	$35
1 in., 1,605 lin. ft., at $0.16	257
1¼ in., 17,550 lin. ft. at $0.18	3,159
1½ in., 45,324 lin. ft., at $0.20	9,065
2 in., 231,632 lin. ft., at $0.24	55,592
2½ in., 4,045 lin. ft., at $0.30	1,214
3 in., 48,955 lin. ft., at $0.41	20,071
4 in., 583,209 lin. ft., at $0.51	297,437
6 in., 106,802 lin. ft., at $0.78	83,306

CAST IRON PIPE

3 in., 18,965 lin. ft., at $0.44	8,345
4 in., 89,850 lin. ft., at $0.62	55,707
6 in., 57,870 lin. ft., at $0.90	52,083
8 in, 22,270 lin. ft., at $1.30	28,951
10 in., 160 lin. ft. at 1.78	285
12 in., 10,975 lin. ft., at $2.20	24,145
16 in., 8,540 lin. ft., at $3.07	26,218
Miscellaneous fittings for above pipe	15,314
	$681,184

15. SERVICES.

SERVICE CONNECTIONS

¾ in., 53 at $11.60	$615
¾ in., 557 at $12.70	7,074
¾ in., 998 at $14.00	13,972
¾ in., 98 at $23.00	2,274
1 in., 2,432, at $14.20	34,534
1¼ in., 5,073 at $15.80	80,153
1½ in., 326 at $17.35	5,656
2 in., 222 at $28.90	6,416
2½ in., 6 at $35.70	214
3 in., 21 at $50.00	1,050
4 in., 3 at $100	300

SERVICE EXTENSIONS

¾ in., 222 at $10.90	2,420
1 in., 480 at $10.50	5,040
1¼ in., 101 at $11.80	1,192
1½ in., 18 at $12.95	233
2 in., 5 at $15.90	80

STUB SERVICES

¾ in., 60 at $9.35	3,450
1 in., 171 at $10.85	1,855
1¼ in., 445 at $11.70	5,207
1½ in., 594 at $12.70	7,544
2 in., 64 at $15.00	960
	$180,239

16. GOVERNORS AND REGULATORS.

Double district station, governors, #02, complete	$426
High pressure line governors, 4 in.	324
High pressure line governors, 2 in. 2 at $88.00	176
Regulators, #4 Reynolds, 66 at $37.30	2,462
Service regulators, 5 light, 1,616 at $4.00	6,464
Regulator chambers, concrete, 20 at $30.00	600
Regulator chambers, wood, 42 at $7.50	315
Governor chambers, wood, 4 at $10.00	40
	$10,807

17. HOUSE METERS.

3 light, 3,388, at $5.25	$17,787
5 light, 7,297 at $5.90	43,052

10 light, 270 at $7.95	$2,147
20 light, 38 at $11.45	435
30 light, 38 at $18.10	688
45 light, 8 at $26.35	211
60 light, 10 at $34.50	345
100 light, 6 at $57.00	342
#5 A, 1,974, at $7.20	14,213
#2 Equitable, 31, at $9.55	296
#4 Equitable, 10 at $10.05	101
#4½ Equitable, 22 at $10.05	221
#6 Equitable, 24 at $17.35	416
3 light prepay, 711 at $9.80	6,968
5 light prepay, 560 at $10.35	5,796
10 light prepay, 37 at $12.15	450
20 light prepay, 4 at $15.30	61
#5 A prepay 293, at $10.00	2,930
Meter connections and service extension inside of house, $13,913 at $5.00	69,565
	$166,024

18. ARC LIGHTS.

Inside arcs, inverted 3 light, 2,393 at $14.10	$33,741
Inside arcs, inverted 5 light, 159 at $16.25	2,584
Outside arcs, inverted 3 light, 200 at $20.80	4,160
Outside arcs, inverted 5 light, 32 at $25.00	800
Inside arcs, standard 4 light, 476 at $12.65	6,021
Outside arcs, standard 4 light, 49 at $21.50	1,054
	$48,360

19. TEAMS AND VEHICLES.

14 assorted horses at $250	$3,500
2 roadster, "Hudson," 4 cylinder, 20 h.p., complete, at $1,350	2,700
1 touring car, "Winton," 6 cylinder, 48.6 h.p., complete	4,100
1 delivery car, "Carter," 2 cylinder, 18 h.p., complete	1,500
1 auto truck, "White," 4 cylinder, 22 h.p., complete	3,250
2 auto truck, "Reo" 1500#, single cylinder, 10 h.p., complete, $725	1,450
8 motorcycles, "Excelsior," single cylinder, 4 h.p., with one tandem seat and shock absorber, at $250	2,000
1 fitter's wagon, double, wooden top	200
1 fitter's wagon, single, wooden top	175
2 dump wagons, double, at $125	250
1 meter wagon, single	240
3 running gear wagons, double at $75	225
1 double running gear wagon with coke box	90
5 open fitter's wagons, single, at $140	700
1 drip wagon, complete, single	325
1 truck, double	225
1 running gear, single, with dump boards	175
1 delivery wagon, single	75
2 service wagons, single, at $125	250
1 light driving buggy	175
6 push carts, at $12.50	75
Harness	700
Tarpaulins, storm covers, blankets, etc.	250
	$22,630

20. TOOLS AND IMPLEMENTS.

Tools in tool room	$4,530
Tools in use in various depts.	2,700
Works tools (mechanical)	750

Retort house tools	$100
Water gas tools	200
Engineering instruments	470
	$8,750

21. TESTING APPARATUS.

Laboratory equipment	$1,814
Recording instruments	1,250
Testing meters, provers, etc.	1,190
	$4,254

22. FURNITURE AND FIXTURES.

Office furniture and fixtures	$12,943
	$12,943
Unloaded total	$1,863,050

23. ENGINEERING, SUPERVISION AND ORGANIZATION EXPENSES.

10% of all preceding items	$186,305

24. INTEREST DURING CONSTRUCTION.

5% of all preceding items	$102,468

25. CONTINGENCIES.

5% of all preceding items	$107,591

26. STORES AND WORKING CAPITAL.

Amount necessary for proper maintenance and operation of property	$80,000

27. BROKERS' FEES.

3.75% of all preceding items	$87,728
Total, exclusive of real estate	$2,427,142

28. REAL ESTATE.

Real estate, including loading charges	153,147
Total, including real estate	$2,580,289

Operating Record. The following operating statistics are averages taken for 13 months from Nov. 1910 to Dec. 1911.

Total consumption	19,998,000 cu. ft.
Cost in holder per M cu. ft.	$0.3722
Distribution cost per M cu. ft.	0.0884
General expense, including taxes per M cu. ft.	0.2798
Total operating expense per M cu. ft.	$0.7404

Comparison of Calorific Values, Coal and Water Gases. The only logical way to present the comparative cost so that it appears in its true light is to show the cost per unit of calorific power derived. Under present conditions about 48% of the total gas manufactured is coal gas, having a calorific energy of approximately 550 B.t.u.; while the remaining 52 per cent. is water gas, having a calorific energy of approximately 660 B.t.u., or 20% greater than that possessed by coal gas. By using these figures in connection with average costs of generating coal and water gas it is seen that the cost of coal gas per 100 B.t.u. is 4.95 cts., while the cost of water gas of similar calorific power is 5.05 cts.

TABLE III. COMPARATIVE COST OF COAL GAS AND WATER GAS

COAL GAS

Item	Monthly average cost per M cu ft. manufactured
Operating labor	$0.1041
Coal carbonized	0.3444
Bench fuel	0.1386
Steam	0.0166
Purifying material	0.0010
Miscellaneous supplies	0.0064
Maintenance land and buildings	0.0017
Maintenance of apparatus	0.0108
Oil, waste and power	0.0020
Gross total	$0.6331
Residuals, sold (credit)	0.3606
Net total	$0.2725

WATER GAS

Item	Monthly average cost per M cu ft. manufactured
Operating labor	$0.0397
Oil	0.1413
Coke	0.0957
Steam	0.0497
Purifying material	0.0011
Miscellaneous supplies	0.0064
Maintenance land and buildings	0.0016
Maintenance of apparatus	0.0115
Oil, waste and power	0.0019
Gross total	$0.3491
Residuals sold (credit)	0.0165
Net total	$0.3326

The result is slightly in favor of coal gas; but the calorific power of coal gas is too low for commercial purposes, and is dependent upon the water gas to enrich it to a commercial basis. As the calorific power of the water gas can be easily regulated by changing the amount of oil used in carburetting it, while that of the coal gas is determined by the quality of the coal used, it can readily be seen why the former is manufactured.

Detailed Cost of a Gas Plant in a City of 25,000. The following data are abstracted from our appraisal report of a public utility

TABLE IV. GENERAL SUMMARY OF THE ESTIMATED COST OF REPRODUCTION OF PROPERTY

1.	Gas making machinery	$ 85,612
2.	Distributing mains (45 miles)	94,637
3.	Services	37,388
4.	Meters	25,162
5.	Buildings	5,677
6.	Electric wiring at plant	103
7.	Tools and instruments	1,862
8.	Horses and vehicles	250
9.	Furniture and fixtures	714
10.	Miscellaneous equipment and apparatus	200
	Total	$251,605

11. Engineering 5% of items 1 to 10 inc.	$ 12,580
12. Business management 5% of items 1 to 10 inc.	12,580
	$276,765
13. Legal expense, 1½% of items 1 to 12 inc.	$ 4,151
	$280,916
14. Interest during construction, 5% of items 1 to 13, inc.	$ 14,046
	$294,962
15. Contingencies, 5% of items 1 to 14 inc.	$ 14,748
	$309,710
16. Broker fees, 5% of items 1 to 15 inc.	$ 15,486
	$325,196
17. Stores and supplies	$ 17,622
18. Working cash capital	10,182
	$353,000
19. Operative real estate	$ 8,700
20. Legal expense, interest during construction and brokerage fees, 12% of item 20	1,044
	$362,744
21. Non-operating real estate	$ 2,225
Total cost as of June 30, 1911	$364,969

NOTE: The costs used in this appraisal are based on prices prevailing previous to the World War.

property which included this gas plant, which supplied 2139 customers, in a western city of 25,000 population, with 37,544,000 cu. ft. annually.

The following table gives weights and prices of certain of the gas plant equipment included in the appraisal.

	Weight, lbs.	Price
1 4 ft. Lowe water gas set	31,000	$ 3,800
1 150 M cu. ft. gas holder	300,000	19,750
1 #3 exhauster, engine and by-pass, consisting of inlet and outlet valves, automatic by-pass valve and connections for same	3,200	638
1 #3 P. & A. tar extractor, with by-pass, consisting of three valves and necessary connections	2,800	440
2 10 ft. by 12 ft. by 11 ft. 6 in. purifiers with 12 in. duplex valve	74,000	5,700
1 66 in. station meter and by-pass consisting of three valves and necessary fittings	9,170	1,300
1 3 ft by 11 ft. condenser	3,660	250
1 3 ft.-4 in. by 14 in. condenser	5,700	415
1 washer 30 ins. by 42 ins. by 28 ins.	4,800	325
1 scrubber 3 ft.-4 ins. by 21 ft.	4,300	270
1 scrubber 4 ft by 18 ft. by 8 ins.	4,800	297
1 purifier 8 ft. by 10 ft. by 3½ ft.	12,500	790
1 oil heater	600	90
1 ¾ in. oil meter	310	90
1 12 in. Connelly governor	850	480
1 42,000 cu. ft. gas holder	130,000	8,200
1 #5 blower for water gas set	550	98

TABLE V. DETAILED ESTIMATED COST OF REPRODUCTION OF PROPERTY

1. GAS MAKING MACHINERY

Benches.	
1 Coal gas bench, half depth, Parker-Russell type consisting of six retorts whose safe daily capacity is 40,000 cu. ft., estimated	$3,500.00
2 Coal gas benches of the Parker-Russell type consisting of six retorts each. Contract price	5,826,00
Extra work on benches	838.25
Total cost of benches	$6,664.25
Water Gas Set.	
1 4 ft. Lowe double superheater apparatus. This consists of 1 generator, 1 carburettor and 1 scrubber, and has a safe daily capacity of 100,000 cu. ft.	$8,904.40
Additional improvements on water gas set	986.23
	$9,890.63
Primary Condenser.	
This is a 5 ft. diameter by 19 ft. high combination air and water primary condenser. This contract also called for a few other changes to be made to the plant including a 9 ft. 6-in. addition to be made to one scrubber and the installation of some 10 in. piping, also six 3-in. sight "U" overflows and a 24 in. by 36 in. drain tank. Contract price	$2,716.00
Additional cost to company	193.44
	$2,909.44
Coal Gas Condensers.	
1 Coal gas condenser, 3 ft. diameter by 11 ft. high. Cost of condenser	$250.00
Installation	25.00
	$275.00
1 Coal gas wrought iron condenser 3 ft. 4 ins. diameter by 14 ft. high. Cost of condenser	$415.00
Installation	41.50
	$456.50
Coal Gas Scrubbers.	
1 Coal gas wrought iron scrubber 4 ft. diameter by 18 ft. 8 ins. Cost of scrubber	$297.00
Installation	53.00
	$350.00
1 Coal gas wrought iron scrubber 3 ft. 4 ins. diameter by 21 ft. high	$300.00
Chollar Washer.	
1 Chollar washer 2 ft. 6 ins. by 3 ft. 6 ins. by 2 ft. 4 ins.	$350.00
Exhauster.	
1 P. H. & F. M. Root's exhauster size 3. The cost of the exhauster is included with 150,000 cu. ft. gas holder.	
1 P. H. & F. M. Root's exhauster Size 4. Cost of exhauster	$ 723.00
Materials	288.52
Labor	92.89
	$1,104.41

Tar Extractor.

1 P. & A. tar extractor — 250,000 cu. ft. capacity, No. 3. The cost of the extractor is included with 150,000 cu. ft. gas holder.

Purifier.

1 Small wet seal purifier, 8 ft. by 10 ft. by 3½ ft. with a capacity of 60,000 cu. ft., (estimated) installed..	$1,000.00
2 Duplex purifiers 10 ft. by 12 ft. by 11 ft. 6 ins., with dry seal covers, beams, columns, oxide elevators, duplex operating valve, 12 in. connections, overhead twist and two layers of trays and dumping spouts.	
Contract price	$5,758.00
Extra charges *	3,493.49
	$9,251.49

Station Meters.

1 American Meter Co.'s 4 ft. by 4 ft. Standard Meter, capacity 90,000 cu. ft., f.o.b. Philadelphia..........	$575.00
Freight and installation	100.00
	$675.00
1 Meter 66 in. with a commercial capacity of 311,000 cu. ft. The price of this is included under the cost of the purifiers.	

Gas Holders.

1 Gas holder, 42,000 cu. ft. The holder and tank are used for a stoarge unit for water gas, (estimated) installed	$12,000
1 Gas holder, 150,000 cu. ft., together with other apparatus. Contract price	$21,954.00
Miscellaneous charges	5,600.69
	$27,554.69
1 Boiler, 30 h.p. horizontal tubular, used for generating steam for the water gas plant	$350.00
1 Boiler, 6 h.p. upright	150.00
1 Duplex steam pump, 3 in. by 2 in. by 4 in. Cost....	33.50
Installation	6.50
	$40.00
1 Duplex steam pump, 4½ ins. by 2¾ ins. by 4 ins. Cost	$51.00
Installation	9.00
	$60.00
1 Duplex steam pump 3½ ins. by 2½ ins. by 3 ins. Cost	$47.50
Installation	7.50
	$55.00
1 Ammoniacal liquor concentrator, capacity for concentrating liquor, resultant from ammoniacal carbonization of 20,000 tons of coal. Total charge......	$2,245.22
1 Oil heater (estimated) installed	$110.00
1 No. 5 Buffalo blower driven by 8-h.p. Erie engine. Price	$266.00
Installation, etc.	18.00
	$284.00

* These extra charges include cost of improvements to Chollar washer and old purifier, also installation of station meter. The price of the station meter itself f.o.b. plant was $1,400.

1 Tar well 10 ft. by 12 ft. by 9 ft., built of 2-in. plank.	
Excavation 40 cu. yds. at $0.50	$20.00
Material	25.00
Labor	2.00
	$47.00
2 Bristol recording gauges	$ 80.00
1 Fairbanks-Morse 6 h.p. gas engines	340.00
1 10 h.p.-G. E. motor. Price motor	170.00
Miscellaneous	37.39
	$207.39
1 No. 6 Sturtevant gas booster	$550.00
Installation	88.92
	$638.92
1 Oil tank, 10,000 gals.	$350.00
3 Bristol pressure gauge, not installed	$105.00

Piping and Covering.

Pipe line, water gas machine to holder, 71 ft. 6 ins., 8 in. riveted pipe at 7 lbs. per foot, 500.5 lbs., 501 lbs. at $0.06	$30.06
7, 8 in. cast iron elbows at $5.53	38.71
Labor erection	21.00
	$89.77
Pipe line, water gas holder to exhauster. 75 ft. 6 in. wrought iron pipe at $0.611	$45.83
4, 6 in. fittings at $0.85	3.40
Labor erection	25.00
	$74.23
Steam pipe.	
165 ft. 1½ in. pipe at $0.765	$12.62
125 ft. 1 in. pipe at $0.0639	7.99
140 ft. 1½ in. covering, $0.15	21.00
Fittings (estimated)	10.00
Labor	35.00
	$86.61
Water pipe.	
175 ft. 2 in. pipe at $0.118	$20.65
Fittings (estimated)	1.50
Labor	5.00
	$27.15
Railing about condensers.	
87 ft. 1¼ in. pipe at $0.0639	$5.56
20, 1¼ in. railing fittings at $0.14	2.80
Labor	3.00
	$11.36
Railing about purifiers.	
60 ft. 1 in. pipe at $0.06	$3.60
15, 1 in. fittings at $0.10	1.50
Labor	2.00
	$7.10
Pipe from coal shed to oil tank.	
145 ft., 3 in. pipe at $0.245	$35.53
Miscellaneous material	18.79
Labor	10.86
	$65.18

Ammonia pipe from tank to side track.	
150 ft. 2 in. pipe at $0.147	$21.75
Fittings	0.99
Labor	8.30
	$31.04
Steam and water-line to ash pans of benches, total	11.49
Water line.	
2 in. pipe from storage tank to works, 170 ft. 2 in. pipe at $0.145	$24.65
Miscellaneous material	4.11
Labor	11.55
	$40.31
Circulating pump to ammonia still.	
62 ft. 1¼ in. pipe	$4.50
Miscellaneous material	0.71
Labor	5.94
	$11.15
Water Tank.	
The old purifiers erected near the Sub-Station and connected to the works by a 1-in. pipe. Tanks measure 7 ft by 7 ft. by 1 ft. 5 ins., built of ¼-in. metal. Total weight 2,730 lbs., at $0.03	$81.90
Erection and pipe line installation	35.55
	$117.45
Miscellaneous small piping not detailed (estimated)	$100.00
Main from station meter to large holder.	
230 ft. 10-in. pipe at $1.22	$270.60
1 10-in. by 6 in. reducer	5.40
1 10-in. Ell double hub	9.00
1 10-in. drip	5.00
2 10-in. 45 degree bends	12.06
Labor	90.00
	$392.06
Main from Governor to Elk Street.	
105 ft. 12-in. pipe at $1.56	$163.80
1 12-in. tee at $8.88	8.88
2 12-in. to 8-in. reducers, at $8.00	16.00
2 8-in. valves at $20.69	41.38
Labor	30.00
	$260.06
Main from Booster to Elk Street.	
50 ft., 8-in. pipe at $0.87	$43.50
217 ft. 6-in. pipe at $0.60	130.20
1 8-in. by 6-in. by 6-in. tee	3.45
2 6-in. valves at $11.29	22.58
Labor	35.00
	$234.73
12-in. Connolly governor, price f.o.b. plant	$480.00
Installation (estimated)	50.00
	$530.00
¾-in. oil meter, price f.o.b. plant	$90.00
Installation (estimated)	10.00
	$100.00
#5 blower for water gas set, price f.o.b. plant, not installed	$98.00
Pumps: 1 Wagner 3 in. by 2 in. by 3 in.; 1 Snow 3 in. by 2 in. by 3 in., estimated	$50.00

Ammonia liquor well, 4 ft. by 12 ft. by 9 ins., built of 3 in. lumber	
Excavation 16 cu. yds. at $1.00	$16.00
Lumber 1,158 ft. b.m. at $25.00 per M.	30.00
	$46.00
Pressure gauge board (estimated)	$12.00
Oxide in purifiers, estimated 4,160 bushels at $0.45	$1,872.00
Total gas making machinery	$85,611.63

2. DISTRIBUTING MAINS

1-in. Wrought Iron Pipe.

Material, 3998 lin. ft. pipe at $0.0639	$255.47
Fittings, 3998 lin. ft., at $0.003	11.99
Total material	$267.46
Labor, excavation and refill, 3998 lin. ft. trench (1 ft. by 2.5 ft.), 370 cu. yds. at $0.75	$277.50
Drayage, 4 tons at 1.5 miles, 6 ton-miles, 6 ton miles at $0.40	2.40
Laying pipe, 3998 lin. ft. at $0.03	119.94
Painting pipe, 3998 lin. ft. at $0.00112	4.48
Total labor	$404.32
Total 1 in. pipe	$671.78

Unit Costs.

Material, cost per ft.	$0.067
Labor, cost per ft.	0.101
Total	$0.168

2-in. Wrought Iron Pipe.

Material, 106,861 lin. ft. pipe at $0.118	$12,609.60
Fittings, 106,861 lin. ft. at $0.0048	512.93
Total material	$13,122.53
Labor, excavation and refill, 106,861 lin. ft. trench (1 ft. by 2.5 ft.), 9895 cu. yds. at $0.75	$7,421.25
Drayage, 214 tons at 1.5 miles — 321 ton miles, 321 ton miles at $0.40	128.40
Laying pipe, 106,861 lin. ft. at $0.03	3,205.83
Painting pipe, 106,861 lin. ft. at $0.00142	151.74
Total labor	$10,907.22
Total 2-in. pipe	$24,029.75

Unit Costs.

Material, cost per ft.	$0.123
Labor, cost per ft.	0.102
Total	$0.225

3-in. Wrought Iron Pipe.

Material, 54,999 lin. ft. pipe at $0.2673	$14,701.23
Fittings, 54,999 lin. ft. at $0.0047	258.50
Total material	$14,959.73
Labor, excavation and refill, 54,999 lin. ft. trench (1 ft. by 2.5 ft.), 5093 cu. yds. at $0.75	$3,819.75
Drayage, 220 tons at 1.5 miles — 330 ton miles, 330 ton miles at $0.40	132.00

Laying pipe, 54.999 lin. ft. at $0.065		3,574.94
Painting pipe, 54,999 lin. ft., at $0.00172		94.20
Total labor		$7,620.89
Total 3-in. pipe		$22,580.62

Unit Costs.

Material, cost per ft.	$0.272
Labor, cost per ft.	0.139
Total	$0.411

4-in. Wrought Iron Pipe.

Material, 45,445 lin. ft. pipe at $0.3355	$15,246.80
Fittings 45,445 lin. ft. at $0.0067	304.49
Total material	$15,551.29
Labor, excavation and refill, 45,445 lin. ft. trench (1 ft. by 2.5 ft.), 4208 cu. yds. at $0.75	$3,156.00
Drayage, 250 tons at 1.5 miles, 375 ton miles, 375 ton miles at $0.40	150.00
Laying pipe, 45.445 lin. ft. at $0.08	3,635.60
Painting pipe, 45,445 lin. ft. at $0.00191	86.80
Total labor	$7,028.40
Total 4-in. pipe	$22,579.69

Unit Costs.

Material, cost per ft.	$0.342
Labor, cost per ft.	0.154
Total	$0.496

6-in. Cast Iron Pipe.

Material, 6305 lin. ft. pipe at 30 lbs. per ft., 189,150 lbs. at $40.00 per ton	$3,783.00
Lead, 526 joint at 8 lbs. per joint, 4208 lbs., at $0.0525 per lb.	220.92
Oakum. 526 joints at 9/16 lbs. per joint, 300 lbs. at $0.09	27.00
Total material	$4,030.92
Labor, excavation and refill, 6,305 lin. ft. trench (2 ft. by 2.5 ft.), 1,168 cu. yds. at $0.75	$876.00
Bell holes, 526 at $0.08	42.08
Drayage, 189,150 lbs. pipe 4,208 " lead 300 " oakum 193,658 " 97 tons at 1.5 miles — 146 ton miles, 146 ton miles at $0.40	58.40
Laying pipe, 6305 lin ft. at $0.03	189.15
Painting pipe, 6305 lin. ft. at $0.00231	14.56
Total labor	$1,180.19
Total 6-in. C. I. pipe	$5,211.11

Unit Costs.

Material, cost per ft.	$0.64
Labor, cost per ft.	0.186
Total	$0.826

6-in. Wrought Iron Pipe.

Material, 6000 lin. ft. pipe at $0.611	$3,666.00
Fittings for 6000 lin. ft. at $0.0712	427.20
Total material	$4,093.20
Labor, excavation and refill, 6000 lin. ft. trench (1.5 ft., by 2.5 ft.), 944 cu. yds. at $0.75	$708.00
Drayage, 57 tons at 1.5 miles — 86 ton miles, 86 ton miles at $0.40	34.40
Laying pipe, 6000 lin. ft. at $0.06	360.00
Painting pipe, 6000 lin. ft. at $0.00231	13.86
Total labor	$1,116.26
Total 6-in. W. I. pipe..........................	$5,209.46

Unit Costs.

Material, cost per ft.	$0.682
Labor, cost per ft.	0.186
Total	$0.868

8-in. Cast Iron Pipe.

Material, 5353 lin. ft. pipe at $0.40 lbs. per ft., 214,120 lbs. at $40.00 per ton	$4,282.40
Lead, 447 joints at 11 lbs. per joint, 4917 lbs. at $0.0525 per lb.	258.14
Oakum, 447 joints at 11/16 lbs. per joint 307 lbs. at $0.09 per lb.	27.63
Total material	$4,568.17
Labor, excavation and refill, 5353 lin. ft. trench (2 ft. by 3 ft.), 1227 cu. yds. at $0.75	$920.25
Drayage, 214,120 lbs. pipe 4,917 " lead 307 " oakum 219,344 " 110 tons at 1.5 miles — 165 ton miles, 165 ton miles at $0.40...	66.00
Bell holes, 447 at $0.08	35.76
Laying pipe, 5353 lin. ft. at $0.03	160.59
Painting pipe, 5353 lin. ft. at $0.00269	14.40
Total labor	$1,197.00
Total 8-in. C. I. pipe	$5,765.17

Unit Costs.

Material, cost per ft.	$0.853
Labor, cost per ft.	0.224
Total	$1.077

NOTE: Fittings are listed separately.

8-in. Converse Lock Joint Pipe.

Material, 8784 lin. ft. pipe at $0.675	$5,929.20
Lead, 550 joints at 8 lbs. per joint, 4400 lbs. at $0.0525 per lb.	231.00
Oakum, 550 joints at ⅝ lbs. per joint, 357 lbs., at $0.09	32.13
Total material	$6,192.33
Labor, excavation and refill, 8784 lin. ft. trench (2 ft. by 3 ft.), 1952 cu. yds. at $0.75	$1,464.00

Drayage, 125,699 lbs. pipe	
4,400 " lead	
357 " oakum	
130,456 " —65 tons at 1.5 mile — 98 ton miles, 98 ton miles at $0.40.	$39.20
Bell holes, 550 at $0.08	45.00
Laying pipe, 8784 lin. ft. at $0.03	263.52
Painting pipe, 8784 lin. ft. at $0.00269	23.63
Total labor	$1,835.00
Total C. L. J. pipe	$8,027.68

Unit Costs.

Material, cost per ft.	$0.716
Labor, cost per ft.	0.198
Total	$0.914

NOTE: Fittings are listed separately.

Valves.

3 6-in. valves at $16.29	$48.87
3 4-in. valves at 10.53	31.59
4 3-in. valves at $6.00	24.00
3 2-in. valves at 3.00	9.00
Total	$113.46

Fittings.

32 8-in. crosses at $5.80	$185.60
20 6-in. crosses at 4.00	80.00
8 8-in. plugs at 1.50	12.00
5 6-in. plugs at 1.00	5.00
2048 lbs. lead at $0.525	107.62
133 lbs. oakum at $0.09	11.97
Drayage	10.00
Labor	35.00
Total	$447.19
Total valves and fittings	$560.65

3. SERVICE CONNECTIONS.

8,584 lin. ft. ¾-in.
198,209 lin. ft. 1-in.
17,280 lin. ft. 1¼-in.
3,628 lin. ft. 1½-in.

3029 Connections, 227,761 lin. ft.	
227,761 lin. ft. at $0.16	$36,441.76
Painting 227,761 lin. ft. at $0.00112	225.09
	$36,696.85
42 Connections, 2688 lin. ft., 2-in.	
2688 lin. ft. at $0.23	$618.24
Painting 2688 lin. ft. at $0.00142	3.82
	$622.06
1 Connections, 135 lin. ft. 4 ins.	
135 lin. ft. at $0.51	$68.85
Painting 135 lin. ft. at $0.00191	0.26
	$69.11
Total service connections	$37,388.02

4. METERS.

880	3	Lt. Prepayment at $10.45	$9,196.00
42	3	" " " 8.70	365.40
426	5	" " " 12.22	5,265.72
140	5	" " " 10.47	1,088.80
4	10	" " " 14.05	56.20
7	10	" " " 12.05	84.35
433	3	Lt. Plain at $6.87	$2,974.71
123	3	" " " 5.12	629.76
461	5	" " " 8.25	3,803.25
42	f	" " " 6.50	273.00
31	10	" " " 10.53	326.43
6	10	" " " 8.53	51.18
12	20	" " " 15.00	180.00
2	20	" " " 12.00	24.00
1	60	" "	55.00
1	60	" "	50.00
1	100	" "	63.95
1	150	" "	95.00
1	200	" "	117.00
1	200	" "	112.00
2	300	" " " 205.00	410.00
		Total meters	$25,161.75

5. BUILDINGS.

Coal Shed.

This is a one-story frame building measuring about 70 ft. by 25 ft. by 25 ft high. There is also an addition about 70 ft. by 17 ft. These buildings are frame, covered with corrugated iron.

Clearing site, grading, etc.	$300.00
8,000 sq. ft. corrugated iron at $6.70 per square	536.00
14,000 ft. b. m. lumber at $25.00 per M.	350.00
Incidentals	100.00
Total	$1,286.00

Old Retort House.

This is a brick building with iron truss roof which is covered with corrugated iron. The general dimensions are 40 ft. by 40 ft. by 25 ft. The walls are 12 ins. thick.

Grading, clearing, etc.	$50.00
60,000 brick at $12.00 per M.	720.00
1400 sq. ft. corrugated iron at $6.70 per sq.	94.00
Pipe trusses	60.00
Incidentals	50.00
Total	$974.00

New Retort House.

This is a frame building covered with corrugated iron. The East wall is of rubble masonry, while the South wall is formed by the old retort house. The general dimensions are 50 ft. by 30 ft. by 26 ft.

Grading, etc.	$200.00
Rubble wall, 56 cu. yds. at $5.00	280.00
4,000 sq. ft. corrugated iron at $6.70	268.00
10,000 ft. b. m. lumber at $25.00	250.00
Floor, etc.	75.00
Incidentals	75.00
Total	$1,148.00

Purifying House.

This is a one-story frame building covered with corrugated iron and measures 65 ft. by 30 ft.

Clearing site, grading, etc.	$250.00
5,000 ft b. m. lumber at $25.00	125.00
5,500 sq. ft. corrugated iron at $6.70	369.00
3,800 brick at $12.00	456.00
Meter room	25.00
Incidentals	75.00
Floor	30.00
Total	$1,330.00

Oxide Platforms.

There are 2 oxide platforms placed one over the other. The upper one is frame covered with corrugated iron. The floor of this one partially forming the roof of the lower one, which is about 40 ft. longer than the upper one. General dimensions of upper platform are 45 ft. by 14 ft.

630 sq. ft. corrugated iron at $6.70	$42.00
1,500 ft. B. M. lumber at $25.00	38.00
Incidentals	10.00
Lower platform	60.00
Total	$150.00

Boiler Room.

This measures 12 ft. by 10 ft. by 8 ft. Three sides and the roof are covered with corrugated iron. The other side being formed by the new retort house.

400 sq. ft. corrugated iron at $6.70 per sq.	$27.00
Lumber	5.00
Total	$32.00

Coke Shed.

This is a frame building open at the sides, the roof being covered with corrugated iron. The general dimensions being 50 ft. by 33 ft.

2,000 sq. ft. corrugated iron at $6.70 per sq.	$134.00
6,000 ft. b. m. lumber at $25.00	150.00
Total	$284.00

Oil House.

This is a frame biulding measuring 6 ft. by 6 ft.

Estimated	$12.00

Bunk House.

This is a frame building measuring 24 ft. by 15 ft. and contains 360 sq. ft. of floor area.

Cost at $0.50 sq. ft.	$180.00

Coal Shed.

This measures about 12 ft. by 10 ft. and is open at the front.

Cost	$10.00

Governor House.

This is a frame building covered with corrugated iron and measured 16 6 ft. by 14.6 ft.

700 sq. ft. corrugated iron at $6.70 per sq.	$47.00
Lumber	10.00
Total	$57.00

Booster House.	
This is a frame building covered with corrugated iron. It measures 13 ft. by 20 ft. One side of this is formed by the 150,000 cu. ft. gas holder, the other partially by the governor house.	
Estimated cost	$25.00
Fence.	
378 lineal feet of board fence, 6 ft. high at $0.50 per lin. ft.	$189.00
Total buildings	$5,677.00

Detailed Cost of a Gas Plant in a City of 15,000. The following is abstracted from one of our appraisal reports of a western Power, Light and Water Co. and is for the "Gas Department." This department furnishes gas for domestic and lighting use to about 1,300 customers in two adjoining cities, having a combined population of 15,000. The system consists of an oil gas generating plant of 100,000 cu. ft. daily capacity, and 25.6 miles of mains.

During 1911 the company distributed 21,898,000 cu. ft. of gas.

Process of Manufacturing Oil Gas. The process of making fuel and illuminating gas from crude oil consists in spraying the oil over the highly heated checkerbrick interior of brick-lined steel generators, much resembling those used in the manufacture of water gas.

The gas is manufactured from absolutely crude oil from the Bakersfield, California, district. The oil now used has a specific gravity of 16° to 17° Baume. A distillation test of a 15° oil used in 1908 gave the following results.

Below 150° F.	6.133%
150° to 300° F.	70,111%
Residue	23,756%

No distillation above 270°.

An analysis of a 15.8° Baume oil (similar to that used) at one of the San Francisco plants in 1908 gave the following results.

Carbon	85.0%
Nitrogen	1.0%
Sulphur	0.8%
Oxygen	1.0%
Hydrogen	12.2%

If the oil contains less than 1% of sulphur, it is very easily purified in oxide purifiers. If above 1%, a large purifying capacity must be provided. Nearly all of the California oils contain a low percentage of sulphur. The iron oxide used as purifier by the Company is made from copperas and lime. Some iron borings are used, but only when they can be obtained cheaply.

In making a run the interior of the generator is heated by an oil flame under a blast to a temperature of 2300° to 2800° F. This takes from 8 to 12 minutes if the generators have not been allowed to cool. The stack valve is then closed, the air cut off and the oil turned onto the hot brick. This part of the operation

lasts from 10 to 20 minutes or until the generator becomes too cool for making further gas. Enough steam is admitted to carry in the oil and to atomize it. Near the end of the run the oil is cut off and steam at boiler pressure admitted for from 1 to 2 minutes to purge the generator.

The generators usually consist of cylindrical steel shells 6 ft. to 16 ft. in diameter and 20 ft. to 40 ft. high. In some cases the generators are in two parts, connected at the bottom in the form of a U. One called the primary to which the blast and oil burners are connected at the top is about .5 as high as the other. This does away with the necessity of arches over the combustion chambers and thus lengthens the life of the fire brick interior.

From the generators the gas is passed through washers, scrubbers and purifiers, much as coal or water gas is handled, except that no condensers are used as the only impurities to be removed are sulphureted hydrogen and lampblack.

The sulphureted hydrogen is taken out by oxide purifiers and the lampblack is washed out in the washers and scrubbers, separated from the water in settling tanks, known as lampblack boxes, and used generally as boiler fuel. In some cases the lampblack is used as fuel in water-gas generators.

The gas produced has the same properties and constituents as good coal-gas.

Description of Plant. The gas system consists of an oil generating plant of 100,000 cu. ft. daily capacity, 25.55 miles of high pressure mains, and 1,686 service connections, 1,277 of which were in use.

The generating plant occupies 26,250 sq. ft. of ground. There are two generators with a combined daily capacity of 500,000 cu. ft. No. 1 is a 300,000 cu. ft. machine, 5 ft. by 8 ft. by 21 ft., originally of the well known "Lowe" type, but remodeled. No. 2 is a 200,000 cu. ft. cylindrical machine, an old scrubber purchased from the San Francisco Gas and Electric Co. being used as the shell. There is a small wash box for each generator. One scrubber of 200,000 cu. ft. daily capacity serves both generators. A single lift, steel holder, set in a wooden tank, receives the gas from the scrubber. Its capacity is 20,000 cu. ft. There are two purifiers consisting of wooden tanks with steel covers and water seals. Gas is stored under a pressure of about 60 lbs. per sq. in. in four steel tanks, having a total capacity of 1,831 cu ft.

The plant is equipped with two boilers, aggregating 120 h.p., a 110,000 gal. wooden oil tank, and a lampblack separator.

A 12 in. by 12 in. motor driven compressor is used for forcing the gas into the high pressure storage tanks. There is a separate blower for each generator, both of which may be driven from the same engine. A motor is also arranged to be belted to either blower. A spare engine-driven compressor has been installed. Provision is thus made for complete operation, by either electricity or steam. Piping, pumps, meters, etc., are provided for the proper handling of the oil and steam.

There is no station gas-meter.

The gas mains are laid with an average cover of 2 ft. 9 ins. A 3 ft. by 1 ft.-6 in. trench is excavated for laying mains. The largest main is 3 ins. in diameter, the small size being made possible by the high pressure (5 to 10 lbs. per sq. in.) maintained for distribution. This pressure is controlled by governors at the storage tanks. Before being laid, the pipe is carefully cleaned, tested, painted with two coats of red lead, and fitted with recessed couplings.

At all times there are a considerable number of services not in use. To reduce the pressure to a proper working value a regulator is installed at each customer's premises. The pressure is varied according to conditions and the appliances used, the range being from 3 to 8 ins. of water — generally about 4 ins. While most of the meters are of the ordinary plain recording type, there are a large number of prepay meters, these being preferred by many customers on account of the fact that they are conducive to economy in the use of gas.

Plant Capacity. The following tables give in condensed form data as to the extent and capacity of the Gas System.

Capacity of Gas Plant Equipment June 30, 1912:

Item	Total capacity
2 Generators	500,000 cu. ft. daily.
1 Scrubber	200,000 " " "
2 Purifiers	100,000 " " "
2 Compressers	500,000 " " "
1 Holder	20,000 " " "
2 Boilers	120 h.p.
2 Engines	55 h.p.
2 Motors	60 h.p.

Gas Plant Distribution System Data June 30, 1912:

Item	Number
Gas mains	25.6 miles
Plain gas meters	1,277
Prepay gas meters	384
Pressure regulators	1,277
Gas services	1,686
Gas customers	1,277
Gas ranges connected	760
Water heaters connected	174
Gas arcs connected	22

Operating Data. The gas companies are required by the State Public Service Commission to provide gas of a calorific power of 550 B.t.u. per cu. ft.

Following are the results of two analyses of the gas.

	CO_2	O	C_2H_4	CO	CH_4	H	N
Analysis #1, Nov. 1911...	3%	2%	7.8%	7.6%	22%	53.7%	2.9%
Analysis #2, Dec. 1911...	3.2%	1.1%	9.7%	7.7%	20.3%	52.4%	4.9%

The company attempts to maintain an illuminating quality of 19 candlepower. No tests of this are made as it is of little importance in the use of gas in modern appliances.

To show as nearly as possible from data obtainable, details of the operating conditions, use of gas, cost of operating, revenue, and earnings of the gas system as now operated, the following

tables have been prepared. The data were taken from the company's monthly operating and financial reports.

TABLE VI. OPERATING DATA

	One year Jan. 1, 1911, to Dec. 31, 1911
Total gas manufactured (not metered) cu. ft.	29,784,900
Total gas consumed, cu. ft.	21,898,000
Losses, per cent. of amount manufactured	26.4%
Pounds of oil carbonized	2,418,193
Gas manufactured per lb. of oil, cu. ft.	12.23
Candle feet per pound of oil	234
B.t.u. per cu. ft. of gas	562*
B.t.u. per lb. of oil	6,873
Pounds of oil per gallon	7.88
Total hours retort operation	3,373
Total hours labor making gas	13,441
Gas made per man per day, cu. ft.	26,853
Pounds of lampblack used as fuel	734,625
Pounds of oil used as fuel	104,359

*November, 1911, to May, 1912.

TABLE VII. FINANCIAL DATA

EXPENSES

	Cost for one year Jan. 1, 1911, to Dec. 31, 1911
COST OF MANUFACTURE.	
Operating:	
Generator fuel	$ 2,586
Boiler fuel	412
Oil at $1.33 per bbl. of 42 gals.	7,158
Purification supplies	317
Water	420
Expense works	625
Manufacturing labor	3,547
Purification labor	64
Electric current at ½c. per kw.-h.	80
	$15,210
Maintenance:	
Gas apparatus	$ 1,220
Steam plant	244
Buildings	221
	$1,685
COST OF DISTRIBUTION.	
Operating:	
Office expense	$ 43
Complaint expense	585
Setting and removing meters	2,177
Electric current	361
	$3,166
Maintenance:	
Mains	$ 772
Services	1,607
Meters	766
	$3,145

	Cost for one year Jan. 1, 1911, to Dec. 31, 1911
COMMERCIAL EXPENSES.	
Collection	$ 506
Office	936
Office salaries	1,502
	$2,944
GENERAL EXPENSES.	
Accidents and damages	$ 3
General expense	1,118
Insurance	132
General salaries	1,361
	$2,554
NEW BUSINESS.	
Advertising	$ 1,084
Soliciting	880
Gas appliances	900
House fitting	161
	$3,025
Total all expenses	$31,729

Maintenance. The gas plant has not been in operation long enough to require a very great outlay for maintenance, except the replacing of the burned out fire brick in the generators.

It is necessary to do this about once a year and the cost runs from $150 to $250 per generator.

The total outlay for maintenance was in 1910 $3,082 and in 1911 $4,830. The entire system is being maintained in good operating condition.

Efficiency and Adequacy of Plant. The gas generating plant is quite efficient and is economically handled. During the year 1911 the average production of gas was 12.23 cu. ft. per lb. of oil. The results of several runs made on a San Francisco plant with the most modern equipment and under the best conditions give an average of only 15.1 cu. ft. per lb. of oil.

Previous to June of 1911 the losses on the gas system were very large as it is difficult to prevent leakage on a high pressure system. At that time a determined effort was made to reduce the losses by making a careful inspection of services, meters, tanks, etc., and stopping all leaks discovered. The losses at once decreased. During the winter of 1911 and 1912 they jumped again. However, when a hot water furnace which was found on the system without a meter was cut off they dropped back and have averaged 12% since December, 1911.

The manufacturing plant is fully adequate to supply the demand for some time, except that it will be necessary to increase the purifier capacity. A much needed improvement is an increase in the holder capacity. A 50,000 cu. ft. holder has already been proposed. This would do away with the necessity of running the generators more than a few hours a day and is expected to reduce the cost of operation of the plant.

The company now runs free services to the customer's meter, in cases where large gas ranges are installed. In other cases the

cost of making the connection is charged. This policy has been varied from time to time. In the beginning services were installed free of charge and as the company now maintains all services, they have been considered as the property of the company in the estimated cost to reproduce the plant.

TABLE VIII. GENERAL SUMMARY OF REPRODUCTION COST

1. Gas mains	$ 50,535
2. Gas services	24,936
3. Gas meters	19,007
4. Gas plant buildings	9,380
5. Miscellaneous buildings	293
6. Gas making and storage equipment	30,746
7. Shop equipment	783
8. Tools and instruments	533
9. Furniture and fixtures	317
	$136,530
10. Engineering, 5% items 1 to 9 inclusive	6,827
11. Business management, 5% items 1 to 9 inclusive	6,826
	$150,183
12. Legal and general expense and taxes, 1½% items 1 to 11 inclusive	2,253
	$152,436
13. Interest during construction, 5% items 1 to 12 inclusive	7,622
	$160,058
14. Contingencies, 5% items 1 to 13 inclusive	8,003
	$168,061
15. Brokerage fees, 5% items 1 to 14 inclusive	8,403
	$176,464
16. Stores and supplies	6,536
17. Working cash capital	1,892
18. Real estate	1,650
19. Legal expense, interest and brokerage fees, 12% item 18	198
Grand total as of June 30th, 1912	$186,740

TABLE IX. DETAILED ESTIMATED COST OF REPRODUCTION OF PROPERTY

1. GAS MAINS

Material:	
Wrought iron pipe, painted, 1 in., 14,625 ft. at $0.069	$ 1,009
Wrought iron pipe, painted, 1¼ in., 36,135 ft. at $0.097	3,505
Wrought iron pipe, painted, 2 in., 79,855 ft. at $0.157	12,537
Casing, painted, 3 in., 4,310 ft. at $0.34	1,465
	$18,516
Elbows, ties, reducing ties, crosses, reducing crosses, expansion joints, drips, caps, and valves	270
	$18,786
Add 2%, omission, waste, etc.	375
Total material	$19,161

Labor:

Excavation and backfill, 134,925 ft. of trench, 22,555 cu. yds. at $1.25	$28,191
Laying 1-in. iron pipe, 14,625 ft. at $0.02	292
Laying 1¼-in. iron pipe, 36,135 ft. at $0.02	723
Laying 2-in. iron pipe, 79,855 ft. at $0.025	1,996
Laying 3-in. iron pipe, 4,310 cu. yds. at $0.04	172
Total labor	$31,374
Total gas mains	$50,535

2. GAS SERVICE.

Taken as all ½-in. services, of an average length of 80 ft. Total number of services, 1,686.

Material:

Iron pipe, ½-in. painted recessed couplings, 134,800 ft. at $0.05	$ 6,744
"Phillips" patent connections, 1,686 at $1.70	2,866
Total material	$ 9,610

Labor:

Excavation and backfill, 117,860 lin. ft. at $0.10	$11,786
Laying and connecting pipe, 134,880 lin. ft. at $0.02	2,697
Making service taps, 1,686 lin. ft. at $0.50	843
Total labor	$15,326
Total gas services	$24,936

3. GAS METERS.

Gas Meters:

3	light	plain	Standard	974	at	$ 5.10	$ 4,967
3	"	"	Maryland	58	"	5.05	293
5	"	"	Standard	182	"	7.10	1,292
5	"	"	Maryland	23	"	5.50	127
10	"	"	Standard	14	"	6.95	97
20	"	"	"	7	"	12.90	90
30	"	"	"	8	"	17.30	138
45	"	"	"	2	"	27.00	54
#3	"	"	Sprague	9	"	10.05	90
3	"	prepay	Standard	252	"	9.10	2,293
3	"	"	Maryland	101	"	8.70	879
5	"	"	Standard	31	"	11.10	344
						1661	$11,664

Pressure Regulators:

One regulator assumed for each meter in service.
All makes and sizes at an average price.

Pressure regulators, 1,277 at $4.75	$ 6,066
Installation meters with regulators, 1,277 at $1.00	1,277
	$ 7,343
Total gas meters	$19,007

4. GAS PLANT BUILDING.

Main Gas Plant Building:

Brick, concrete floors, corrugated iron roof, ½ pitch. 32 ft. 6 ins. by 87 ft. by 18 ft. high.

Foundation — concrete, 56 cu. yds. at $8.50	$ 476
Brick (in place), 196,126 (est.) at $24.00/M	4,708
Concrete floors, 2,752 sq. ft. at $0.15	413
Roof timbers (in place), 1,760 f.b.m., at $30.00/M	53
Roof iron, 650 lbs. at $0.04	26

Corrugated iron roofing, 3,670 sq. ft. at $0.05	$184
Floor and stair to meter room, 2nd floor, 1,280 f.b.m., at $30.00/M	38
Windows, 11	100
Doors, 4	80
Stone window ledges and door sills	65
Addition 12 ft. by 14 ft. by 9 ft. high brick, cor. iron roof	231
	$6,374

Purifier House:

Brick, cor. iron, pitched roof:	
Plank floor, 32 ft. by 32 ft. by 16 ft. to eaves.	
Foundations, 20 cu. yds. at $8.50	$ 170
Brickwork, 65,184 brick at $24.00/M	1,564
Plank floor, 3,000 F.B.M., at $30.00/M	90
Roof rafters, etc., 680 F.B.M., at $30.00/M.	20
Roof corrugated iron, 1,308 sq. ft. at $0.05	65
Door, stairs, etc.,	30
	$1,939

Lampblack Shed:

Frame; corrugated iron roof, 24 ft. by 28 ft.	
Area, 672 sq. ft., at $0.10	$ 67
Lampblack boxes; 1 9½ ft. by 64 ft. by 30 ins.—9 compartments, 1 6 ft. by 11 ft. by 4 ft.	
Planking, 3010 f.b.m., at $30.00/M	90
Iron, 300 lbs. at $0.04	12
Excavation, 8 ft. by 14 ft. by 5 ft., 20 cu. yds. at $1.00	20
	$189

Purifier Storage Shed:

Rough shed, tar paper roof, 18 ft. by 100 ft. by 7 ft.	$ 441
Concrete floor, 48 ft. by 18 ft., 864 sq. ft. at $0.15	130
Concrete wall, 2 ft. 6 ins. by 62 ft.	32
	$603

Hose house; frame, 8 ft. by 10 ft.	$ 35
Regulator house; frame, 8 ft. by 10 ft.	35
Small oil tank house; frame, 20 ft. by 4 ft.	30
	$100

Gas Shop:

Rough frame building, shingle roof, 30 ft. by 20 ft. by 8 ft. high, plank floor, 600 sq. ft., at $0.20	$ 120

Lighting, Wiring, etc., at Plant:

22 lights—(wiring, sockets and lamps in place)	$ 40
Lockers	15
	$55
Total gas plant buildings	$ 9,380

5. MISCELLANEOUS BUILDINGS.

Storeroom Building:

Single story frame, plank floor, ½ pitch.	
Tar paper roof. Decks and shelving inside, 75 ft. by 40 ft. by 12 ft. to eaves. 3,000 sq. ft. at $0.40	$ 1,200
Shed on end of building	40
Lighting, 15 drop lights (open wiring)	23
Water piping, etc.	12
Platform 3-in. floor, 12 ft. by 45 ft., 2,700 ft. b.m., at $30.00	81
5 ft. board fence, 550 ft. at $0.20	110
	$1,466

Divided on basis of space occupied.

2/5 to water,
2/5 to electrical,
1/5 to gas,
1/5 interest in storeroom buildings $293
Total miscellaneous buildings $293

6. GAS MAKING AND STORAGE EQUIPMENT.

1 Lowe #5 crude oil gas generator (known as #1 generator),
1 Washer, 4 ft. by 5 ft. by 3 ft. 6 ins.
1 Scrubber, 5 ft. by 8 ft. by 18 ft. 6 ins.
1 Gas holder, 40 ft. by 18 ft., 20,000 cu. ft. capacity.
4 Cylindrical boiler iron gas tanks, 29 ft. by 4 ft. 6 ins. diam.
2 Wooden purifier tanks, 10 ft. by 10 ft. by 5 ft. 6 ins., riveted steel covers and seals.
1 Rix compressor, 12 ins. by 12 ins. (belt driven),
1 Boiler in brick setting, 40 h.p.,
1 Stack for boiler and generator,
2 Chaplin Fulton pressure governors, 2 in.,
1 Sturtevant #5 blower,
1 Jewell engine, 10 h.p.
1 Boiler feed pump,
1 Oil pump,
8-in. pipe from scrubber to gas holder,
8-in. pipe holder to purifiers,
6-in. main purifiers to compressors,
3-in. piping, compressors to pressure tanks, then to governors and to line.
Oil piping to #1 generator, meters, etc.,
Blast connections blower to gas generator,
All of the above apparatus was erected in place ready for operation (in 1905), under contract for the sum of..$20,400
30 h.p., 220 v. 3 phase, 850 r.p.m. motor * with starter in place and wired ....$ 440

Additions to and remodeling Lowe gas generator:

In 1910, the Lowe generator purchased under the contract in 1905, was completely remodeled. The height of the shell was increased from 13 ft. to 18 ft. A 3-ft. water heating tank was added on top making the final dimensions 5 ft. by 8 ft. by 21 ft. All interior brickwork was replaced. All burners, blast connections and gas connections to washer were replaced. The above work was done at a cost of $2,337.55. Estimated addition to cost of generator by above improvements ....$ 1,800

Foundations for above machinery:

Concrete foundations for generator, scrubber, etc., 963 cu. ft. ....$ 259

No. 2 Generator:

Old scrubber purchased from the San Francisco Gas and Electric Co. and converted into a generator and washer. Generator 24 ft. by 6 ft. diam. Washer 4 ft. by 6 ft. diam. ....$	400
Labor cutting off scrubber and placing on cars San Francisco	197
Work on gas generator	382
Foundation for generator	218
Brickwork for gas generator, labor and material.......	902
Freight on generator, San Francisco to plant..........	80
Labor setting, connecting, etc., by local company (estimated)	400
	$2,579

* Motor drives Rix compressor.

Boiler (80 h.p.) with stack: f.o.b. San Francisco	$	875
Freight, brickwork and erection, estimated		485
		$1,360
Engine: (45 h.p. Atlas high speed) f.o.b. San Francisco	$	440
Freight		50
Installation		50
		$540
Ingersoll Rand compressor: (12¼ in. by 12 ins.) (estimated) — installed	$	950
Belt		60
Belt tightener		25
		$1,035
Blower for No. 2 Generator:		
30 h.p. 3 place motor with speed control connection. Motor mounted on wooden platform. Pipe to gas generator, estimated cost		$545
Piping, Pumps, Oil Equipment, etc., Added to Plant since Original installation: (All estimated).		
Iron pipe, 8 ins., 215 ft. at $0.22	$	47
Ells, 3 ins., 10 ft. at $0.50		5
Gate valves, 3 ins., 4 ft. at $4.50		18
Angle valve, 3 ins., 1 ft. at $8.00		8
Pipe, 4 ins., 134 ft., at $0.35		47
Ells, 4 ins., 3 ft. at $0.60		2
Gate valve, 4 ins., 1 ft. at $7.80		8
Pipe, 1½ ins., 75 ft. at $0.08		6
Ells, 1½ ins., 4 ft., at $0.12		1
Valves, 1½ ins., 3 ft. at $1.50		4
Pipe, 1 in., 170 ft. at $0.05		8
Ells, 1 in. 5 ft. at $0.10		1
Labor on above pipe 30% of material		431
Wooden oil storage tank, 30 ft. diam. by 22 ft. high, tar paper roof, cost estimated, complete		950
Steel oil tank ¼-in., 15 ft. by 4 ft. diam. (complete)		214
Concrete well, 5 ft. by 6 ft. by 6 ft.		35
1 Duplex oil pump		60
1 Lowe oil trap		50
4 Oil meters, at $25.00		100
Covered pipe, 3 ins. in place, 90 ft. at $0.50		45
Pipe, ¼ in., in place, 100 ft. at $0.02		2
Pipe, ½ in., in place, 50 ft. at $0.04		2
Pipe, ¾ in., in place, 150 ft. at $0.05		7
3 Bristol recording pressure gauges		125
		$1,788
Total gas making and storage equipment		$30,746

Detailed Cost of a Gas Plant in a City of of 2,600. The following data is abstracted from our appraisal report of a company which supplies gas for lighting and cooking purposes in a western city of 2,600 population.

The plant consists of a 72,000 cu. ft. oil gas generator of the Lowe Type — of the necessary scrubbers, purifiers, piping, oil storage tanks, boilers, etc., and of 1 single lift 21,000 cu. ft. gas holder in a brick tank. The company now has in service 7.9 miles of .75 in. to 4 in. wrought iron and cast iron mains, and 212 meters.

The processes of manufacture are almost identical with those in use at the plant in the city of 15,000 population, previously de-

scribed in this chapter. The oil used for generating being the same as that used in that plant and costs $1.62 per bbl. in the storage tanks.

The company serves from 200 to 225 customers. The principal use of the gas service is for cooking. Practically all lighting is done with electricity.

Capacity of Plant. The following table gives in condensed form the extent and capacity of the plant as of June 30, 1912.

Oil gas generators	1	72,000 cu. ft.
Washers	1	72,000 cu. ft.
Scrubbers	3	72,000 cu. ft.
Purifiers	2	172,000 cu. ft.
Holders	1	18,600 cu. ft.
Boilers	1	30 h.p.
Mains	7.9 miles	
Meters in service	212	

Following is a table of operating data for the month of June, 1912, which may be taken as a fair average of operating conditions for the year.

Gas made	248,900 cu. ft.
Gas used at works and office	1,300 " "
Gas consumed, customers' meters	224,300 " "
Gas lost	23,300 " "
Gas lost, per cent. of gas made	9.2%
Oil, carbonized	14,398 lbs.
Oil burned, heating retorts	6,131 "
Oil used, total	20,429 "
Gas made per lb. of oil	12.1 cu. ft.
Oil used as boiler fuel	1,794 lbs.
Cost of oil	$0.0386 per gallon

The following table is an analysis of Operating Expenses from the Company's financial statement for June, 1912.

OPERATING EXPENSES

Manufacture.	
Fuel generating	$30.05
" boiler	8.78
" gas making	70.87
Purifying material	12.10
Labor	93.45
Miscellaneous	5.75
	$220.70
Maintenance	$ 2.03
Distribution	1.67
Commercial expense	53.62
General expense	35.87
New business, expenses	13.14
Total expense	$327.03

TABLE X. GENERAL SUMMARY OF ESTIMATED COST OF REPRODUCTION OF PROPERTY*

1. Gas mains	$11,945
2. Gas services	4,905
3. Gas meters	3,230
4. Gas plant buildings	2,545

5. Gas making and storage equipment	$14,485
6. Tools and instruments	33
7. Furniture and fixtures	41
	$37,184
8. Engineering, 5% of items 1 to 7 inclusive	1,859
9. Business management, 5% items 1 to 7 inclusive	1,859
	$40,902
10. Legal and general expense and taxes, 1½% of items 1 9 inclusive	613
	$41,515
11. Interest during construction, 5% of items 1 to 10 inclusive	2,076
	$43,591
12. Contingencies, 5% items 1 to 11 inclusive	2,179
	$45,770
13. Brokerage fees, 5% items 1 to 12 inclusive	2,288
	$48,058
14. Stores and supplies	1,571
15. Working cash capital	767
16. Real estate	750
17. Legal and general expense and taxes 12% of item 16	90
Grand total as of June 30, 1912	$51,236

TABLE XI. DETAILED ESTIMATED COST OF REPRODUCTION OF PROPERTY

1. GAS MAINS

Material:	
Pipe:	
¾-in. wrought iron pipe, 3,265 ft. at $0.052	$ 170
1-in. wrought iron pipe, 13,755 ft. at $0.069	949
1¼-in. wrought iron pipe, 16,400 ft. at $0.097	1,591
2-in. wrought iron pipe. 3,010 ft. at $0.157	473
3-in. wrought iron pipe, 600 ft. at $0.27	162
4-in. cast iron pipe, 4,230 ft. at $0.41	1,734
	$5,079
Fittings	39
Lead joints, c. i. pipe, 5½ lbs. per joint, 1,750 lbs. at $0.06	105
2% commission, waste, etc.	104
	$5,327
Labor:	
Excavation and backfill, 41,260 ft. trench, 7,640 cu. yds. at $0.75	$ 5,730
Laying pipe, w.i., ¾-in., 3,265 ft. at $0.02	65
Laying pipe, w.i., 1-in., 13,755 ft. at $0.02	275
Laying pipe, w.i., 1¼-in., 16,400 ft. at $0.02	328
Laying pipe. w.i., 2-ins., 3,010 ft. at $0.025	75
Laying pipe, w.i., 3-ins., 600 ft., at $0.03	18
Laying pipe, c.i., 4-ins., 4,230 ft. at $0.03	127
	$ 6,618
Total gas mains	$11,945

2. GAS SERVICE.

Material:	
Iron pipe, 1-in., 25,440 ft. at $0.069	$1,757
"Phillips" patent service connections, 318 ft. at $1.80..	572
	$2,329
Labor.	
Excavating and backfilling trench, 19,080 ft. at $0.10..	1,908
Laying pipe, 25,440 ft. at $0.02	509
Making service taps, 318 ft. at $0.50	159
	$2,576
Total service connections	$4,905

3. GAS METERS.

Material:	
Gas meters, 268 at $8.10	$2,171
Labor:	
Installing gas meters, 212 at $0.75	159
Total gas meters	$3,230

4. GAS PLANT BUILDING.

Main Building: 28 ft. by 95 ft., 16 ft. to eaves.	
1 to 2 pitch roof.	
Frame, corrugated iron roof, 25 ft. 6 ins. by 28 ft.	
Brick, corrugated iron roof, 30 ft. by 28 ft.	
Frame, shingle roof, 40 ft. by 28 ft.	
Foundations, concrete, 30 cu. yds. at $9.00	$ 270
Lumber in frame portion and timber under corrugated iron roofs, 12,649 ft. b.m. at $35.00/M	443
Brick, in walls and partitions, 52,248 at $25.00/M.	1,306
Corrugated iron roof, 2,217 sq. ft. at $0.055	122
Shingle roof, 9,000 shingles at $5.00/M.	45
Doors, 4 at $16.00	64
Windows, 5 at $10.00	50
Lean-to frame, 12 ft. by 12 ins., 144 sq. ft. at $0.50	72
Lean-to frame, 12 ft. by 14 ins., 168 sq. ft. at $0.40	68
Lighting	35
	$2,475
Gas Meter House: 5 ft. 7 ft. by 6 ft. high.	
Frame, walls and roof filled with saw-dust, tar paper roof, 35 sq. ft. at $2.00	70
Total gas plant buildings	$2,545

5. GAS MAKING AND STORAGE EQUIPMENT.

Oil Gas Generator: 72,000 cu. ft. capacity, arranged to be fired from either end of a "U" shaped generating chamber. Lowe type, rebricked to a special design, 6 ft. by 6 ft. by 10 ft. high, 5/16-in. shell, complete in place with quick changing stack valves, double set of oil burners and steam inlets, washer connections and two stacks	$1,850
Washer and Scrubbers:	
1 Cylindrical washer, 32 ins. by 40 ins. in place....$	100
1 Cylindrical scrubber, 4 ft. by 16 ft. high, in place	350
2 Cylindrical scrubbers, 3 ft. by 8 ft. high, in place, at $175.00	350
	$ 800

Gas Piping:	
8-in. cast iron pipe, 10 ft. at $1.40	$ 14
8-in. cast iron crosses, flanged, 6 at $12.00	72
8-in. cast iron tees, 2 at $9.00	18
8-in. Wrought iron pipe, screw, 34 ft. at $0.90	31
6-in. Wrought iron pipe, screw, 170 ft. at $0.65	110
6-in. Wrought iron tees, screw, 2 at $2.25	5
6-in. Wrought iron ells, screw, 5 at $2.00	10
6-in. Gate valves, screw, 2 at $24.00	48
4-in. Wrought iron pipe, 44 ft. at $0.38	17
4-in. Wrought iron crosses, 8 at $1.60	13
Labor on piping, 25% of material	84
	$422
Purifiers:	
1 10-ft. by 10 ft. by 2½ ft., steel shell, in place	$ 800
1 11 ft. by 11 ft. by 6 ft., steel shell, in place	1,500
	$2,300
Station Meter:	
On 4-in. main, 3 ft. drum	$275
Blast Equipment:	
1 Sturtevant #3 blower	$ 35
1 Motor 7½ h.p. with starter	160
1 Engine, 10 h.p.	150
3-in belt, 25 ft. at $0.30	8
Connections, blower to generator	20
Platforms, foundations, pulleys, wiring, etc.	35
Labor installing blower, motor and engine	40
	$448
Boiler:	
30 h.p. tubular, set in brick, with 24-inch stack, complete place	$450
Water, Steam and Oil Piping; Oil and Water Pumps, etc.:	
1 Compressor, 3 ins. by 5 ins.	$70
1 Oil pump, single acting, 3 ins. by 6 ins. by 6 ins.	60
1 Centrifugal pump, 2 ins.	90
2 Motors, G. E., 2 h.p., 3 phase	100
1 Oil tank, 300 gals.	90
1 Pressure gauge	10
2 National oil meters, at $35	70
1 Oil filter	20
Iron pipe, ½-in., 150 ft. at $0.04	6
Iron pipe, ¾-in., 100 ft., at $0.05	5
Iron pipe, 1-in., 165 ft. at $0.06	10
Iron pipe, 1½-in., 100 ft. at $0.09	9
Iron pipe, 2-in., 320 ft., at $0.12	38
Valves, ¾-in., 4 at $0.90	4
Valves, 1-in., 3 at $1.10	3
Valves, 1½-in., 3 at $1.40	4
Valves, 2-in., 3 at $2.00	6
Labor on piping, pumps, etc.	94
	$689
Generator and Scrubber Foundations:	
Concrete, 24 cu. yds. at $10.00	$240
Lampblack Box:	
Lumber, 1,840 ft. b.m. at $35.00/M.	$64
Iron, 495 lbs. at $0.05	25
	$89

Water Storage Tank and Well:	
Water tank.	
Wood stave tank, 20 ft. diam. 10 ft. high, redwood staves and bottom, 3,108 ft. b.m. at $52.00/M.	$162
Iron bands, 1,872 lbs. at $0.05	93
Labor assembling and placing tank	75
Tower.	
Timber, 2,675 ft. b.m. at $30.00/M.	80
Iron, 190 lbs. at $0.05	9
Well.	
Excavation, 5 ft. by 5 ft. by 20 ft., 18 cu. yds. at $1.00	18
Timbering, 1,200 ft. b.m. at $32.00/M	38
Drilled well, 200 ft. deep at $2.00	400
	$875
Oil Tanks.	
Wood tank, same as water tank above, except set on sills and lowered into the ground about 2 ft., excavation, 23 cu. yds. at $0.50	$12
Sills, 648 ft. b.m. at $25.00/M.	16
Tank in place	290
Shingle roof over tank	33
3 steel tanks, 16 ft. long, 4 ft. 6 ins. diam. at $200.00	600
Excavation and installation	40
	$991
Gas Holder:	
Steel holder in cement lined brick tank, set in ground about 12 ft., 21,500 cu. ft. capacity.	
Excavation, 873 cu. yds., at $0.75	$ 655
Brick in tank, 47,080 at $25.00/M.	1,171
Concrete bottom of tank, 6 ins. thick, 31 cu. yds. at $10.00	310
Cement plaster, lining tank	120
Framework and guides, cast iron, 9,000 lbs. at $0.04	360
Steel, 8,688 lbs. at $0.08	695
Steel tank, #12 reinforced, steel, 22,024 lbs. at $0.08	1,762
Painting, 8,300 sq. ft. at $0.01	83
	$ 5,156
Total gas making and storage equipment	$14,485

Cost of Reproduction of the Properties of the Kings County Lighting Company. Table XII, derived from "Exhibit No. 17," Case No. 1273 of the Public Service Commission, 1st District New York, gives the estimated cost of reproduction of the properties of the Kings County Lighting Company, N. Y. Details of certain of the accounts included in this table are given in Table XIII which has been prepared from further material in the above mentioned exhibit.

TABLE XII. ESTIMATED COST OF REPRODUCTION OF THE PROPERTIES OF THE KINGS COUNTY LIGHTING COMPANY

Account	Contract cost
General structures	$ 20,482
Furnaces, boilers and accessories	25,221
Water gas sets and accessories	82,353
Misc. power plant equipment	2,041
Works and station structures	201,462
Holders	255,675

Purification apparatus	$27,663
Accessory equipment at works	70,605
Trunk lines and mains	712,351
Gas services	166,151
Gas meters	127,429
Gas meter installation	24,539
Municipal gas lighting fixtures	31,892
Gas engines and appliances	1,181
Gas tools and implements	....
Gas laboratory equipment	1,454
Sub-total, construction accts.	$1,750,660
Land devoted to gas operations	251,281
General equipment	12,036
Total, fixed capital accounts	$2,013,977
Floating capital and operating assets	53,885
Engineering administration and incidentals, 15%	209,855
Total, reproduction cost of the operating property	$2,277,717

TABLE XIII. DETAILS OF ESTIMATED COSTS OF REPRODUCTION OF THE KINGS COUNTY LIGHTING COMPANY

BOILERS, FURNACES AND ACCESSORIES

1 B. & W. 215 h.p. boiler	$ 3,041.80
2 B. & W. 106 h.p. boiler	3,050.73
2 B. & W. 106 h.p. boiler	3,426.73
2 Worthington feed water pumps	250.26
1 Oil tank	3.50
1 Water barrel	1.00
1 Steel stack	831.88
1 Steel stack	812.00
1 Steel stack	840.00
1 Berryman feed water heater	392.50
Coal handling machinery-misc.	475.68
3 Coal cars	450.00
Coal conveying machinery	320.72
Wooden split pulley	15.00
Solid iron pulley	6.00
Rubber comp. belting	20.00
Coal handling machinery, track, etc.	1,757.50
1–3 Ton Hower Ry. platform scale	242,00
Coal hopper	101.59
1 Single vertical engine	240.00
Coal hopper with screen	125.00
1 Mast and gaff	865.81
1 Clam-shell bucket	400.00
1 Rawson & Morrison Mfg. Co. hoist	750.00
Levers, etc., hoisting engine	16.98
1 75 h.p. vertical boiler	824.50
1 50 h.p. vertical boiler	597.90
1 100 h.p. Mason horizontal boiler	1,905.54
1 Cameron feed water pump	230.00
1 Turbo blower std. damper regulator	69.00
25 ft. 1½-in. steam rubber hose	21.88
10-ft. 1-in. steel jointed wire covered steam hose	11.20
20-ft. 1¾-in. wire bound steam hose	23.20
1 Wooden ladder, 12 ft.	2.76
2 Iron wheelbarrows	10.00
2 Water pails	.60
Rack for irons	4.30
4 12-ft. hose	10.00
4 12-ft. slice bars	7.00

4 Schoop shovels	$3.44
1 Stack 5 ft. dis., 125 ft. high	750.00
Net cost	$22,928.00
Contractors' profit, 10%	2,293.00
Contract cost	$25,221.00

WATER GAS SETS AND ACCESSORIES

1 12-ft. Williamson vertical single unit generator	$24,012.97
1 8-ft. Lowe generating set	8,959.21
2 8-ft. Lower generating sets	19,077.91
2 Condensers	4,752.08
2 Condensers	5,411.08
2 Berryman oil heaters	500.00
2 90-h.p. high speed center crank automatic engines	4,579.63
2 No. 11 blowers	956.12
180 ft. leather belting	234.00
Miscellaneous gauges, etc.	58.53
1 2-ton hydraulic elevator	840.00
Blast piping	1,072.41
4 Charging cars	588.00
1 90-h.p. Terry turbine blower	2,790.25
1 Coal spout	2.25
1 2-ton elevator	925.00
2 Coal buggies	120.00
1 Coal car	50.00
1 Coal yoke	10.24
1 Wheelbarrow	5.00
Miscellaneous gen. tools	121.58
Net cost	$74,866.26
Taken as	$74,866.00
Contractors' profit, 10%	7,487.00
Contract cost	$82,353.00

HOLDERS

1 2,000,000 cu. ft. holder	$148,570.95
1 500,000 cu. ft. holder	51,244.60
1 107,000 cu. ft. holder	17,045.46
1 100,000 cu. ft. holder	15,571.05
Net cost	$232,432.06
Taken as	$232,432.00
Contractors' profit, 10%	23,243.00
Contract cost	$255,675.00

TRUNK LINES AND MAINS

Mains:	Unit price
1¼-in., 264 ft. at $0.1839	$ 48.55
1½-in., 3,706 ft., at $0.2024	750.09
2-in., 2,937 ft., at $0.2246	549.65
3-in., 13,011 ft., at $0.3150	4,098.47
4-in., 359,146 ft., at $0.4150	149,045.59
6-in., 365,208 ft., at $0.600	219,124.80
6-in., 42 ft., W. I., at $0.748	31.42
8-in., 19,108 ft., at $0.876	16,738.61
8-in., 111 ft., W. I., at $1.176	130.43
12-in., 48,668 ft., at $1.352	65,799.14
10-in., 70 ft., W. I., at $1.666	116.62
16-in., 6,966 ft., at $2.040	14,210.64
20-in., 9,377 ft., at $2.796	26,218.09
24-in., 61 ft., at $3.694	225.33
	$497,197.43

Fittings:	
Crosses, at $0.027 per lb.	$ 4,855.92
Tees, at $0.027 per lb.	1,347.36
Elbows, at $0.027 per lb.	438.09
Reducers and increasers at $0.027 per lb.	903.57
Caps and plugs at $0.027 per lb.	718.92
Sleeves, at $0.027 per lb.	24.44
	$8,288.30
Pavement:	
Ashphalt, 30,325.51 sq. yds. at $3.00	$ 90,976.53
Asphalt block, 2,727.05 sq. yds., at $3.50	9,544.67
Belgian block, 5,524.56 sq. yds. at $.50	2,762.28
Brick, 1,441.58 sq. yds. at $2.50	3,603.95
Granite, 1,444.98 sq. yds., at $.50	722.49
Macadam, 39,308.02 sq. yds., at $.75	29,481.01
	$137,090.93
Valves, pits and drips:	
Drips, at $0.027 per lb.	$ 3,936.20
Valves (at manufacturers' quoted prices)	889.90
Pits (at estimated prices)	186.93
	$5,015.03
Net cost, Acct. No. 231	$647,591.69
Taken as	$647,592.00
Contractors' profit, 10%	64,759.00
Contract cost	$712,351.00

GAS METERS

Goodwin:	
3 light, 431 at $5.25	$ 2,262.75
5 light, 156 at $6.30	962.80
10 light, 22 at $8.75	192.50
20 light, 17 at $12.60	214.20
30 light, 2 at $19.25	38.50
45 light, 5 at $29.40	147.00
60 light, 7 at $38.50	296.50
100 light, 3 at $61.25	183.75
A. M. Co.:	
3 light, 3,010 at $125.25	15,802.50
5 light, 16,294 at $6.30	102,652.20
10 light, 76 at $8.75	682.50
20 light, 78 at $12.60	982.80
30 light, 39 at $19.25	750.75
45 light, 21 at $29.40	617.40
60 light, 15 at $38.50	577.50
100 light, 13 at $61.25	796.25
200 light, 2 at $125.50	251.00
Reeves, 5 light, 1 at $6.30	6.30
U. S. M. Co., 5 light, 1 at $6.30	6.30
N. Y. Imp. M. Co., 5 light, 2 at $6.30	12.60
Total No., 20,197.	
Net cost also contract cost	$127,429.10
Taken as	$127,429.00

GAS METER INSTALLATION

Net cost also contract cost:	
Installation of 19,631 gas meters at $1.25	$24,538.75
Taken as	$24,539.00

TABLE XIV. NET COST OF TRUNK LINES AND MAINS

COST PER TRENCH FOOT OF GAS MAINS INSTALLED

WROUGHT IRON

	Sizes	1-in.	1¼-ins.	1½-ins.				
Excavation	Depth, ft.	2.7	2.7	2.8	2.8	3.4	3.4	3.6
	Width, ft.	1.5	1.5	1.5	1.5	2.0	2.0	2.0
	Cu. yds.	0.15	0.15	0.16	0.16	0.25	0.25	0.27
	Cost per cu. yd.	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Cost per trench foot	Excavation	$0.128	$0.128	$0.136	$0.136	$0.213	$0.213	$0.23
	Laying	0.002	0.002	0.002	0.002	0.035	0.035	0.04
	Pipe	0.0388	0.0529	0.0634	0.0846	0.487	0.914	1.377
	Haul	0.001	0.001	0.001	0.002	0.013	0.013	0.019
Total cost per trench foot		$0.1698	$0.1839	$0.2024	$0.2246	$0.748	$1.175	$1.666

COST PER TRENCH FOOT OF GAS MAINS INSTALLED

CAST IRON

	Sizes	3-ins.	4-ins.	6-ins.	8-ins.	10-ins.	12-ins.	16-ins.	20-ins.	24-ins.
Excavation	Depth, ft.	2.9	3.0	3.3	3.6	3.7	3.9	4.2	4.6	5.1
	Width, ft.	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5	3.0
	Cu. yds.	0.16	0.17	0.185	0.27	0.28	0.29	0.39	0.425	0.57
	Cost per cu. yd.	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Cost per trench foot	Excavation	$0.136	$0.145	$0.158	$0.23	$0.238	$0.247	$0.332	$0.362	.485
	Laying	0.014	0.019	0.028	0.035	0.044	0.054	0.077	0.128	.209
	Lead	0.025	0.033	0.05	0.065	0.083	0.092	0.117	0.15	.18
	Yarn	0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.005	.007
	Pipe	0.134	0.21	0.35	0.526	0.725	0.924	1.46	2.08	2.72
	Haul	0.005	0.007	0.012	0.018	0.025	0.032	0.05	0.071	.093
Total cost per trench foot		$0.315	$0.415	$0.600	$0.876	$1.118	$1.352	$2.040	$2.796	$3.694

TABLE XV. COST OF CAST IRON MAINS

EXCAVATION FOR MAINS

Size, ins.	Trench Width ft.–ins.		Trench Depth ft.–ins.		Cross-sectional area in sq. ft.	Cu. yds. per lin. ft. of trench
3	1	8	3	6	5.83	.216
4	1	8	3	6	5.83	.216
6	1	10	3	8	6:74	.250
8	2	0	3	10	7.67	.284
10	2	4	4	0	9.33	.346
12	2	6	4	2	10.40	.385
16	2	10	4	6	12.75	.472
20	3	2	4	10	15.30	.566
24	3	6	5	2	18.10	.670

WEIGHT OF CAST IRON MAINS

Size, ins.	Weight per length, lbs.	Additional weight per length add 2%, lbs.	Weight per ft. used, lbs.
3	180	183.6	15.3
4	228	232.6	19.4
6	360	367.2	30.6
8	504	514.1	42.8
10	670	683.4	56.9
12	870	887.4	74.0
16	1,300	1,326.0	110.5
20	1,800	1,836.0	153.0
24	2,450	2,499.0	208.3

Weight includes bells; 2 per cent. is added for overweight.
Average cover is figured at 3 ft.
Excavation, back-filling and hauling excess dirt at $0.75 per cubic yard.
Cartage at $2.00 per ton average all kinds of material on as much of material as would be handled twice.
For specials add 4 per cent. of cost of pipe.

COST OF CAST IRON MAINS

Size, ins.	Cost of pipe	Cartage at $2.00 per ton	Labor laying	Excavation, back-filling and hauling	Joints, materials	Specials	Totals
3	$0.219	$0.015	$0.020	$0.162	$0.020	$0.009	$0.45
4	0.278	0.019	0.020	0.162	0.026	0.011	0.52
6	0.438	0.031	0.040	0.188	0.035	0.018	0.75
8	0.612	0.043	0.050	0.213	0.044	0.024	0.99
10	0.814	0.057	0.060	0.260	0.061	0.033	1.29
12	1.060	0.074	0.080	0.288	0.074	0.042	1.62
16	1.581	0.111	0.160	0.354	0.109	0.063	2.38
20	2.189	0.153	0.250	0.425	0.152	0.083	3.25
24	2.981	0.208	0.400	0.502	0.215	0.119	4.43

CAST IRON PIPE PRICES

Price f.o.b. cars per ton	$27.00
6 per cent. store-room expense	1.62
Total per ton	$28.62

TABLE XVI. UNIT PRICES OF WROUGHT IRON GAS MAINS

Size, ins.	Trench width ft.-ins.	Trench depth ft.-ins.	Cu. yds. excavation per lin. ft.	Cost pipe	Cost fittings, drips, etc.	6 per cent. store room expense on pipe and fittings	Cartage	Labor laying	Excav. and bk. flg.	Total
1	1 8	3 2	.196	$0.0380	$0.0140	$0.0031	$0.0020	$0.0219	$0.1470	$0.2260
1¼	1 8	3 2	.196	0.0529	0.0160	0.0041	0.0025	0.0228	0.1470	0.2444
1½	1 8	3 2	.196	0.0620	0.0180	0.0048	0.0030	0.0226	0.1470	0.2574
2	1 8	3 3	.201	0.0830	0.0210	0.0063	0.0040	0.0689	0.1510	0.3342

Cost of Service Connections. The following data were taken from Exhibit No. 17, Case No. 1273, Appraisal of Kings County Lighting Company, N. Y.

Based on observation of costs of labor and materials, shown in company's records, the average cost of fittings per service, was found to be	$0.35
On the same basis, the average cost of labor, per foot of service, was found to be	0.07640
The cost of hauling was estimated at	0.00178
Making total labor cost, per foot of service	$0.07818

Unit Costs of Gas Mains. In Table XIV is given the derivation of the net unit prices used in Table XIII, Trunk Lines and Mains, as abstracted from Exhibit No. 17, Case No. 1273, Appraisal of Kings County Lighting Co., N. Y.

Tables XV and XVI show the development of unit prices of gas mains as introduced by Wm. A. Baehr in Exhibit No. 29 in the above mentioned case.

Table XVII gives the development of the cost of Lead Joints as used in Table XV.

TABLE XVII. COST OF LEAD JOINTS FOR CAST IRON MAINS

Size, ins.	Weight, lead, lbs.	Weight, yarn	Cost per joint	Cost per foot of joint
3	4.5	0.25	$0.238	$0.020
4	6	0.25	0.313	0.026
6	8	0.40	0.421	0.035
8	10	0.50	0.526	0.044
10	14	0.60	0.732	0.061
12	17	0.80	0.892	0.742
16	25	1.00	1.203	0.109
20	35	1.30	1.819	0.152
24	50	1.75	2.593	0.215

COST OF MATERIAL

Lead	5c at the work
Yarn	5.3c. at the work

Detailed Cost of Gas Services. Table XVIII gives the detailed cost of services as submitted in evidence by Wm. A. Baehr at the hearing of the Kings County Lighting Co., N. Y.

Effect of Length on Cost of Laying 2 in. Gas Main. Table XIX prepared from actual costs on some 147 different pipe laying jobs extending over a period from 1903 to 1911, shows a decided tendency for lower costs as the length of pipe increases. The apparent in average costs for the 401–500 and 601–700 distances is mainly due to a larger percentage of the more recent jobs with the higher rates of pay.

Cost of Relaying Pavement. The following data were abstracted from evidence submitted by Wm. A. Baehr at the hearing of the Kings County Lighting Co., N. Y. The prices are based on a paving contractor furnishing all tools, machinery, labor, and material necessary for relaying pavement in trenches to be excavated

and back-filled by the gas company to the sub-grade of the pavement in place.

The prices are based on the assumption that men taking up the pavement will not cover concrete, brick, and cushion sand which has been removed from the pavement, with the excavated earth,

TABLE XVIII. DETAILED COST OF GAS SERVICES

Size, ins.	Pipe	Fittings	Six per cent. store-room-expense on pipe, valves, and fittings	Cartage	Labor, laying and tapping	Excavation and back-filling	Gas stop	Service sleeves	Total
¾	$1.30	0.16	$0.09	$0.10	$1.90	$6.94	....	....	$10.49
1	1.90	0.23	0.13	0.10	2.00	6.94	....	....	11.30
1¼	2.60	0.31	0.17	0.10	2.10	6.94	....	....	12.22
1½	3.10	0.37	0.21	0.10	2.15	6.94	....	....	12.87
2	4.15	0.50	0.28	0.10	2.30	6.94	$2.44	$2.44	20.11
3	8.70	1.40	0.58	0.15	2.60	6.94	3.16	3.40	26.57
4	12.40	1.49	0.83	0.35	3.00	6.94	6.45	3.40	34.86

The average length of service is taken at 50 ft. and is based on the average length of service, laid from 1906 to 1910.

Cartage is taken at $1.00 per ton and excavation and back-filling at $0.75 per cubic yard.

The cost of fittings was taken as 12 per cent. of the cost of the pipe.

Gas stops, 2 in., iron cock, brass plug. Gas stops, 3 and 4 in., iron cock, brass washers.

Average width of trench, 2 ft. Average depth of trench, 2 ft., 6 ins.

TABLE XIX. EFFECT OF LENGTH ON COST OF LAYING 2-IN. GAS MAIN

Length of pipe laid, ft.	Number of jobs, included	Labor cost per foot		
		Max.	Min.	Average
1– 50	18	$0.3525	$0.0710	$0.1423
51–100	23	0.1836	0.0420	0.0942
101–200	45	0.1897	0.0462	0.0923
201–300	27	0.2750	0.0480	0.0859
301–400	13	0.0953	0.0602	0.0756
401–500	15	0.1750	0.0643	0.1086
501–600	4	0.1105	0.0341	0.0696
601–700	2	0.1179	0.0943	0.1017

and will leave them convenient for replacing in the pavement. Also that in removing pavement with sand, pitch or asphalt filler, the men will not destroy more than 10 per cent. of the brick. To these figures the cost of cutting through the pavement should be added.

In using the above costs the following overcuts in trenches are to be allowed:

1. Granite block on sand and portion concrete base — waste and labor, etc., only	$1.00	per sq. yd.
2. Asphalt on concrete base	3.00	per sq. yd.
3. Vitrified brick on edge	2.60	per sq. yd.
4. Common brick on edge	1.50	per sq. yd.
5. Macadam	.75	per sq yd.
6. Granite block on sand-base, laid	2.50	per sq. yd.

In using the above costs the following overcuts in trenches are to be allowed.

Asphalt	6 ins.	Granite	10 ins.
Belgian block	8 ins.	Macadam	0 ins.
Brick	16 ins.		

Cost of Buildings and Equipment of a Large Gas Plant. Tables XX and XXI were introduced by Wm. W. Randolph as Exhibits "A" and "B" in the hearing of the Kings County Lighting Co., N. Y.

EXHIBIT "A"

	Cost new
Generator House No. 1	$ 16,100
52 ft. 8 ins. by 50 ft. 2 ins. by 33 ft. 0 ins., ground floor to truss chord, two story building, brick walls, gable roof monitor type corrugated iron on steel on steel trusses. Including machinery foundations. Also included with this building is the runway between No. 1 and No. 2 houses.	
Generator House No. 2	41,000
95 ft. 6 ins. by 53 ft. 0 ins. by 48 ft. 11 ins., ground floor to truss chord, two story building, brick walls, gable roof monitor type slate on steel on steel trusses. Including machinery foundations. Also included with this building is pit partly under Generator House No. 2, and partly under Wash Room.	
Boiler House, Engine House, Exhauster House, Tar Tank House and Condenser House	45,900
Boiler House, 53 ft. 1 in. by 42 ft. 0 ins. by 16 ft. 8 ins. ground floor to truss chord, one story building, brick walls, gable roof corrugated iron on steel on steel trusses. Including machinery foundations.	
Engine and Exhauster House, 50 ft. 4 ins. by 41 ft. 0 ins. by 25 ft. 6 ins. ground floor to truss chord, two story building, brick walls, gable roof slate on wood on wood trusses. Including machinery foundations.	
Tar Tower House, 43 ft. 0 ins. by 26 ft. 4 ins. by 89 ft. 0 in. bottom of settling wall to eaves, three story building, brick walls, peaked roof slate on wood. Including machinery foundations. Also included with this building are the tar wells under it.	4
Condenser House, 44 ft. 4 ins. by 41 ft. 0 ins. by 24 ft. 2 ins. ground floor to truss chord, two story building, brick walls, gable roof, slate on wood on wood trusses. Including machinery foundations.	
Purifier House	14,400
67 ft. 4 ins. by 49 ft. 4 ins. by 27 ft. 0 ins. ground floor to truss chord, two story building, brick walls, gable roof monitor type slate on wood on steel trusses.	
Repair Shop and Stable	12,300
67 ft. 0 ins. by 41 ft. 0 ins. by 22 ft. 6 ins. high ground floor to truss chord, two story building, brick walls, gable roof, slate on wood on wood trusses.	
Office and Meter House	17,900
40 ft. 0 ins. by 44 ft. 0 ins. by 37 ft. 10 ins. ground floor to truss chord, three story building, brick walls, gable roof slate on wood on wood trusses. Including machinery foundations.	

Coal Shed	$62,500
108 ft. 2 ins. by 52 ft. 0 ins. by 52 ft. 7 ins. brick floor to eaves, steel and wood construction, roof monitor type tar and gravel on wood. This building includes runways from coal shed to Houses No. 1 and No. 2.	
Coal Tower House on Dock:	
Included with coal handling machinery.	
Artesian Well House	2,100
14 ft. 0 ins. by 14 ft. 0 ins. by 22 ft. 0 ins. basement floor to eaves, brick walls, roof slate on wood, gable type.	
Men's Room House (Wash Room)	4,800
30 ft. 8 ins. by 31 ft. 2 ins. by 24 ft. 3 ins. ground floor to truss chord, two story building, brick walls, roof tar and gravel on wood.	
Valve and Boiler House at Holder Station	7,200
65 ft. 2 ins. by 27 ft. 0 ins. by 14 ft. 0 ins. boiler house floor to truss chord; 23 ft. 4 in. valve house from basement floor to truss chord. Brick walls, roof (large ventilator) part slate on wood, part tin on wood. Including machinery foundations.	
Dock (Pier):	
Frame construction, 582 ft. 6 ins. long	24,800
Fences and paving	10,000
	$259,000
20 per cent. Overhead Charges	51,800
Total Buildings	$310,800

TABLE XXI. COST OF GAS PLANT EQUIPMENT EXHIBIT "B"

	Cost new
GENERATING APPARATUS:	
3 8 ft. 6 ins. Lowe water gas sets to the outlet of washer, with 8 ft. 6 ins. diam. Generators and 8 ft. 0 ins. diam., carburetters and superheaters; 2 located in generator house No. 1, and 1 in generator house No. 2	$ 29,700
1 Williamson set of water gas apparatus. Diam. of generator 12 ft., diam. of superimposed twin carburetter and superheater 14 ft, total height 46 ft. 4 ins.	22,000
BOILERS:	
4 106 h.p. Babcock & Wilcox boilers, water tube, including boiler room piping and 2 steel stacks 39 ins. diam. by 120 ft. high. Located in boiler room.... 1 215 h.p. Babcock & Wilcox water tube boiler, including boiler room piping and 1 steel stack 39 ins. diam. by 122 ft. 6 ins. high. Located in boiler room	18,680
1 90 h.p. vertical tubular boiler including steel stack 2 ft. diam. by 40 ft. high. Located in hopper house on dock. Included with coal handling machinery....	
1 50 h.p. vertical tubular boiler including steel stack 20 ins. diam. by 25 ft. high. Located in valve house at the 65th Street Holder Station	700
1 100 h.p. horizontal tubular boiler including steel stack 30 ins. diam. by 65 ft. high. Located in valve house at the 65th Street Holder Station	2,090

Scrubbers:	
1 primary scrubber 4 ft. by 7 ft. by 20 ft. high. Located in generator house No. 2	$ 770
1 shaving scrubber 10 ft. diam. by 27 ft. 9 ins. high, including foundation. Located in yard	3,000
1 shaving scrubber 10 ft. diam. by 25 ft. high, including foundation. Located in yard	2,500
2 scrubbers 7 ft. diam. by 22 ft. 1 in. high, including foundation. Located in yard	4,620
Condensers:	
2 condensers 7 ft. diam. by 22 ft. 1 in. high, including foundations. Located in yard	6,820
2 condensers 7 ft. diam. by 22 ft. 1 in. high. Located in condenser room	5,280
Tar and Ammonia Extractors:	
1 P. & A. tar extractor with 16-in. connections. Located in tar house	2,200
1 standard rotary washer scrubber 7 ft. diam. by 12 ft. 3½ ins. long. Located in condenser house	4,180
Purifiers:	
4 purifiers 16 ft. by 24 ft. by 7 ft. 6 ins. deep. Located in purifier house	20,350
Holders:	
1 relief holder in steel tank, capacity 100,000 cu. ft., including foundation. Located in yard	18,600
1 storage holder in steel tank, capacity 100,000 cu. ft., including foundation. Located in yard	19,000
1 storage holder in steel tank, capacity 500,000 cu. ft., including foundation. Located at 65th Street Holder Station	53,700
1 storage holder in steel tank, capacity 2,000,000 cu. ft., including foundation. Located at 65th Street Holder Station	175,500
Exhausters and Blowers:	
1 No. 10 Roots exhauster and 1 13 in. by 12 in. direct connected N. Y. safety vertical engine. Located in condenser room	3,300
1 No. 8 Roots exhauster and 1 10 in. by 12 in. direct connected N. Y. safety vertical engine. Located in engine room	1,850
2 No. 6 Roots exhausters and 2 7 in. by 9 in. direct connected Oil City Boiler Works, vertical engines. Located in engine room	2,680
2 No. 11 Buffalo Forge blowers and 2 13 in. by 12 in. Sturtevant engines, double belted. Located in engine room	4,840
1 N. Y. blower and 1 90 h.p. Terry turbine direct connected, including 6½ in. by 12 in. by 12 in. Smith-Vaile condenser pump. Located in Generator House No. 2	3,020
1 shaving blower and 1 6 in. by 6 in. Sturtevant vertical engine (belted). Located in loft over stable. Including piping, etc., to shaving blower	820
1 turbo blower 15 in. diam., connected to Spencer damper regulator. Installed on boilers Nos. 1 and 2. Included with boilers.	
Pumps:	
2 6 in. by 4 in. Worthington duplex pumps. Located in boiler room	250

1 7 in. by 7 in. by 13 in. Cameron simplex pump. Located in basement of engine room	$350
1 6 in. by 5¾ in. by 6 in. Worthington duplex pump. Located in basement of engine room	160
1 10 in. by 10½ in. by 18 in. Cameron simplex pump. Located in Hopper house in dock	690
1 7½ in. by 6 in. by 10 in. Worthington duplex pump. Located in Artesian well house	270
1 5 in. by 4 in. by 8 in. Davidson simplex pump. Located in basement of the engine room	130
1 6 in. by 3 in. by 7 in. Cameron simplex pump. Located in basement of the engine room	140
2 4½ in. by 2¾ in. by 4 in. Worthington duplex pumps. Located in basement of engine room	165
2 6 in. by 5¾ in. by 6 in. Worthington duplex pumps. Located in tar house	320
1 6 in. by 3 in. by 7 in. Cameron simplex pump. Located in valve room 65th Street Holder Station	140

STATION METERS:

1 11 ft. 3 ins. by 11 ft. 3 ins. station meter located in office building	5,170
1 equitable proportional meter with 16 in. connections. Located in office building. Capacity 150,000 cu. ft. per hour	1,200
1 Westinghouse air meter No. 12, located in the engine room	80

ELEVATORS:

1 steam hydraulic elevator, located in generator house No. 2	
1 steam hydraulic elevator, located in purifying house	3,330
1 elevator with crane engine hoist located in generator house No. 1	

SCALES:

1 6-ton wagon scale. Located outside office building. Including pit, etc.	500
1 4-ton platform scale. Located in coal shed	160
1 4-ton track scale. Located in hopper house on dock. Included with coal handling machinery.	

COAL HANDLING APPARATUS:

1 grab bucket hoist and cableway complete, consisting of steel mast and gaff, clamshell bucket, drum hoist with 617 ft. of steel trestle and double cable tracks including 4 3-ton cars, located on dock. Also included with this is hopper house on Dock R. R., track scales, engines and 90 h.p. boiler	33,000

COAL BUGGIES:

4 side drop cars, 2000 lbs. capacity. Located in generator house No. 2	770
2 side drop cars, 1000 lbs. capacity. Located in generator house No. 2	100
2 2-wheel coal buggies. Located in generator house No. 1	100

SHOPS:

Machine shop equipment	
Blacksmith shop equipment	2,200
Carpenter shop equipment	
Meter shop equipment	
Laboratory equipment	1,100

TANKS, WELLS, ETC.	
1 steel oil tank 15 ft. diam. by 15 ft. high, capacity 20,386 gals. Including foundation. Located in the yard	$750
1 steel oil tank 35 ft. diam. by 35 ft. high. Including foundation. Capacity 251,881 gals. Located in the yard	8,250
1 steel well water tank 13 ft. diam. by 20 ins. high. Capacity 19,858 gals. Located in tar tower	550
2 steel tar tanks 10 ft. diam. by 6 ft. high. Capacity each 3,500 gals. Located in tar tower	440
1 settling well 40 ft. diam. by 12 ft. deep, brick with two brick partitions. Capacity 112,755 gals. Located in yard	4,400
1 brick tar well under tar house 32 ft. 6 ins. by 13 ft. by 14 ft. Included with buildings. Capacity 35,000 gals.	
1 brick tar well under tar house 32 ft. 6 ins. by 14 ft. Included with building. Capacity 18,000 gals.	
1 brick tar well under tar house 23 ft. by 6 ft. 2 ins. by 14 ft. Included with building. Capacity 14,850 gals.	
2 driven pipe wells at works 1 driven pipe well at Holder Station	1,100
MISCELLANEOUS:	
1 feed water heater 1 ft. 6 ins. diam. by 6 ft. 8 ins. high. Berryman type. Located in the boiler room 1 feed water heater 1 ft. 6 ins. diam. by 4 ft. high. Berryman type. Located in the tar tower 2 oil heaters 2 ft. diam. by 6 ft. high, Berryman type. Located in generator house No. 1	550
1 Bristol indicating and recording pyrometer, located in the office and connected to the Williamson water gas apparatus	440
1 3 in. type "G" Worthington water meter. Located in office basement	120
1 1¼ in. Worthington oil meter. Located in tar house	80
1 incinerator for burning refuse. Located in office basement	110
1 20 in. Smith & Sayre governor. Located in valve room 65th Street Holder Station	530
Gauges — Miscellaneous	550
Yard connections — piping, valves, valve boxes, manholes, etc.	55,000
Street department tools and tool wagon	600
Rented arc lamps — 136 inside, 41 outside	1,450
48th Street office equipment 48th Street shop equipment	3,750
General stable equipment	6,000
	$541,165
20 per cent. overhead charges	108,233
Total machinery	$649,398

Miscellaneous Data Pertaining to Various Complete Plants. *Massachusetts.* Tables XXII–XXV are made up from the Annual Report of the Gas and Electric Light Commissioners of Massachusetts for the year ending June 30, 1916. From Table XXIII it is possible to tell whether the companies make coal gas, water gas, or both. Tables XXIV and XXV give in detail the expenses of manufacture and distribution.

TABLE XXII.

Corporate Name	Localities supplied	Population	Av. price	Cu. ft. gas made	Daily capacity of works	Greatest output
Amherst Gas Co.	Amherst	5,558	$1.42	3,176,290	150,000	80,400
	Pelham	493				
Citizens' Gas, Elect. & Pwr. Co.	Nantucket	3,166	2.02	6,309,270	50,000	39,960
Norwood Gas Co.	Norwood	10,977	1.54	23,464,200	150,000	97,500
Spencer Gas Co.	Spencer	5,994	1.50	27,090,800	150,000	113,600
Attleboro Gas Lt. Co. Corp'n.	Attleboro	18,480	1.00	74,046,900	300,000	249,000
Clinton Gas Lt. Co.	Clinton	13,192	1.40	24,412,500	285,000	96,000
Gardner Gas, F. & Lt. Co.	Gardner	16,376	1.78	16,895,397	50,000	74,480
Woburn Gas Lt. Co.	Woburn	16,410	1.26	22,506,000	110,000	80,000
Gloucester Gas Lt. Co.	Gloucester	24,478	1.10	82,837,200	725,000	335,400
Northampton Gas Lt. Co.	Northampton	21,654	1.01	82,456,600	450,000	285,000
Arlington Gas Lt. Co.	Arlington	14,889	1.14	115,799,900	1,300,000	444,300
	Belmont	8,081				
	Winchester	10,005				
Beverly Gas & El. Co.	Beverly	22,950	1.19	98,399,100	775,000	387,000
	Danvers	11,177				
Fitchburg Gas & El. Lt. Co.	Fitchburg	39,656	0.992	157,357,000	1,400,000	591,000
Haverhill Gas Lt. Co.	Haverhill	49,450	0.823	332,722,000	2,000,000	1,187,000
	Groveland	2,377				
	Merrimac	2,202				
Pittsfield Coal Gas Co.	Pittsfield	39,607	0.94	222,781,400	1,750,000	712,400
	Dalton	3,858				
Salem Gas Lt. Co.	Salem	37,200	1.01	225,127,294	1,800,000	785,500
	Peabody	18,625				
Brockton Gas Lt. Co.	6 towns totaling	93,925	1.08	402,671,600	3,000,000	1,461,200
Cambridge Gas Lt. Co.	Cambridge	108,822	0.805	983,351,000	8,000,000	4,009,000
	Somerville (port)	67,847				
Fall River Gas Works	Fall River	124,791	0.814	703,490,000	5,050,000	2,600,900
	Somerset	3,377				
Lawrence Gas Co.	Lawrence	90,259	0.863	549,806,500	5,312,000	2,121,800
	Andover	7,978				
	Methuen	14,007				
	No. Andover	5,956				
Worcester Gas Lt. Co.	Worcester	162,697	0.761	1,008,691,000	7,600,000	3,519,000

TABLE XXIII. DATA FROM MASSACHUSETTS PLANTS

	Miles of mains	Consumers per mile of main	Gas sold per consumer	Tons of coal carbonized	Feet of gas per ton of coal	Process used	Materials used in generator	Quantity used, tons	Materials used for making steam	Quantity used, tons	Enricher used	Quantity used, gals.	Meters in use
Amherst	20.2	36	16,343	.....	.....	Lowe	Anthra.	326	Bit.	219	Gas oil	56,128	723
Citizens	3.0	173	10,621	691	9,131	....	......	....	......	....	......	....	523
Norwood	24.4	74	11,948	2,104	11,154	....	......	....	......	....	......	....	1,793
Spencer	18.0	47	12,894	.....	.....	Lowe	Anthra.	639	Bit.	417	Gas oil	97,113	845
Attleboro	26.7	122	21,757	6,662	11,115	....	......	....	......	....	......	....	3,253
Clinton	14.3	96	16,053	.....	.....	Lowe	Anthra.	622	Bit.	197	Gas oil	79,187	1,363
Gardner	21.6	59	10,544	.....	.....	Lowe	Anthra.	309	Bit.	192	Gas oil	78,061	1,277
Woburn	19.2	61	17,804	2,268	9,923	....	......	....	......	....	......	....	1,170
Gloucester	38.9	93	21,881	.....	.....	Lowe	Anthra.	1,319	Bit.	544	Gas oil	249,441	3,628
Northampton ..	41.7	85	21,080	3,496	10,359	Lowe	Coke	782	Coke	510	Gas oil	184,566	3,557
Arlington	80.7	69	18,462	.....	.....	Lowe	Coke	1,942	Coke & Bit.	525	Gas oil	384,612	5,514
Beverly	76.4	79	14,749	3,600	10,681	Lowe	Coke	1,076	From El. Dep't.		Gas oil	219,435	6,051
Fitchburg	69.0	119	17,528	8,787	11,534	Lowe	Coke	833	From El. Dep't.		Gas oil	229,809	8,237
Haverhill	106.1	114	25,519	.....	.....	Lowe	Coke	5,172	Bit.	131	Gas oil	1,094,051	12,108
Pittsfield	87.7	106	23,332	7,260	10,195	Lowe	Coke	520	Coke & Bit.	3,341	Gas oil	603,701	9,312
Salem	86.9	148	16,536	11,984	10,507	Lowe	Coke	2.012	Coke	1,796	Gas oil	355,103	12,812
Brockton	220.5	90	18,256	17,559	11,056	Lowe	Anthra.	647	Bit.	831	Gas oil	756,825	19,865
Cambridge	177.6	211	25,298	64,670	11,399	Lowe	Coke	3,959	Gas Dep't.		Gas oil	1,044,593	37,475
Fall River	151.5	178	23,918	29,550	11,623	Lowe	Coke	4,418	Bit. & Coke	1,602	Gas oil	1,263,498	26,901
Lawrence	184.3	131	21.117	32,554	11,684	Lowe	Coke	2,899	Coke	756	Gas oil	680,465	24,125
Worcester	215.0	151	29,564	52,985	11,610	Lowe	Coke	6,077	Miscel.	11,825	Gas oil	1,417,404	32,365

TABLE XXIV. EXPENSES OF MANUFACTURE, PER THOUSAND CUBIC FEET MADE

	Coal	Enrichers	Purifiers	Water	Wages	Station expenses, tools, etc.	Repairs and works' structures	Renewals, mach'y, and equip't.	Total	Net cost in holder, less residuals sold
	cts.	cts.	cts.	cts.	cts.	cts.	cts.	cts.	cts.	cts.
Arlington	9.98	14.17	0.28	0.22	6.70	0.66	0.48	0.30	32.77	32.77
Fitchburg	28.32	6.59	0.85	0.39	7.43	1.33	0.79	3.82	49.52	35.70
Haverhill	9.22	15.48	0.19	0.31	4.08	0.35	0.04	0.38	30.05	29.40
Pittsfield	16.56	10.64	0.12	0.43	8.64	0.43	1.66	3.03	41.51	39.89
Salem	19.81	4.73	0.16	0.44	9.48	0.67	1.96	3.56	40.80	33.87
Brockton	25.68	7.70	0.12	0.55	8.25	1.03	1.33	1.29	45.96	35.01
Cambridge	24.57	4.19	0.31	0.39	4.95	0.14	0.31	6.74	41.61	26.49
Fall River	18.17	7.19	0.17	0.08	6.90	0.70	0.35	2.70	36.26	21.26
Lawrence	29.86	5.32	0.04	0.19	10.06	...	2.24	1.70	49.40	34.73
Worcester	22.74	5.13	0.20	0.46	4.20	6.76	0.14	4.05	43.68	34.65

TABLE XXV. EXPENSES OF DISTRIBUTION AND OFFICE AND OTHER OPERATING EXPENSES, PER THOUSAND CUBIC FEET SOLD

	Wages	Tools and appliances	Gas stoves	Repairs of mains and services	Repairs and renewals of meters	Public lamps	Other expenses	Total	Office expenses	Taxes	Misc. expenses
	cts.	cts.	cts.	cts.	cts.						
Arlington	2.41	2.07	0.93	1.37	1.18	...	...	7.96	18.79	7.24	2.16
Fitchburg	4.71	2.36	5.28	1.85	1.15	...	...	15.35	13.51	10.28	2.02
Haverhill	1.44	1.52	0.57	1.32	1.65	1.44	...	7.93	11.80	7.28	1.85
Pittsfield	3.38	1.47	0.32	2.16	2.12	...	...	9.45	11.24	6.32	1.93
Salem	2.80	0.30	0.32	2.16	3.18	...	...	8.75	9.30	11.92	1.36
Brockton	4.90	9.47	...	2.78	1.63	...	...	18.78	10.51	10.05	1.89
Cambridge	4.58	0.71	0.71	2.20	2.18	0.51	...	10.89	6.17	9.57	2.58
Fall River	2.61	1.80	0.41	2.18	2.59	...	...	9.59	7.56	10.68	1.36
Lawrence	1.29	...	2.18	1.65	3.44	0.10	0.04	8.70	8.37	10.22	1.86
Worcester	2.14	0.39	1.14	1.68	2.51	...	...	7.86	3.60	7.26	1.40

TABLE XXVI. DATA FROM WISCONSIN PLANTS

Name of company	Location	Population	M cu. ft. consumption per 100 population	Consumption per 100 population	Miles of main	% loss of gas in distribution	M cu. ft. lost per mile of main
Wis.-Minn. Lt. & Pr. Co.	Chippewa Falls	8,893	96.4	6.2	10.3	12.6	12.0
Watertown Gas & El. Co.	Watertown	8,829	333.3	17.0	20.8	13.0	213.5
Ashland Lt., Pr. & St. Ry.	Ashland	11,594	123.3	8.5	15.5	13.5	145.5
Beloit W., G., & El. Co.	Beloit	15,125	461.5	19.1	33.6	12.4	295.3
Eau Claire Gas Lt. Co.	Eau Claire	18,310	249.8	16.7	37.1	7.9	108.7
Eastern Wis. Ry. & Lt. Co.	Fond du Lac	18,797	346.0	17.1	40.1	8.4	148.8
New Gas Light Co.	Janesville	13,894	503.3	20.9	32.3	24.1	54.0
Manitowoc Gas Co.	Manitowoc	13,027	342.8	17.1	28.9	11.9	212.3
Menominee & Mar. Lt. & Tr. Co.	Marinette	14,610	87.2	4.5	13.7	15.9	193.9
Wausau Gas Co.	Wausau	16,560	178.1	11.4	25.6	5.3	67.0
Wis. Tr., Lt., Ht., & Pr. Co.	Appleton	28,588	304.8	14.6	53.0	11.5	214.3
Wis. Pub. Ser. Co.	Green Bay	25,236	250.3	11.6	60.2	17.2	218.3
Wis. Gas & Elec. Co.	Kenosha	21,371	632.2	19.5	42.2	21.3	869.0
Madison Gas & Elec. Co.	Madison	25,531	767.0	24.6	67.6	10.7	348.1
Sheboygan Gas Lt. Co.	Sheboygan	26,398	223.6	14.5	39.2	8.9	150.1
La Crosse Gas & El. Co.	La Crosse	30,417	315.7	14.4	56.7	18.6	389.3
Oshkosh Gas Lt. Co.	Oshkosh	33,062	325.8	13.7	43.0	4.4	114.4
Wis. Gas & Elec. Co.	Racine	38,002	721.3	24.2	81.4	8.5	497.6
Superior W., Lt. & Pr. Co.	Superior	40,384	218.3	8.8	38.7	...	....

TABLE XXVII

	Coal gas: Coal carbonized, tons	Coal gas: Yield per lb. of coal, cu. ft.	Coal gas: Coke produced per ton of coal carbonized, lbs.	Coal gas: Coke used for bench fuel, per ton of coal carbonized	Coal gas: Average selling price coke per ton at works	Coal gas: Tar products per ton coal carbonized, gals.	Coal gas: Average selling price tar per gallon at works	Coal gas: Ammonia per ton coal carbonized	Coal gas: Average selling price per unit of ammonia	Water gas: Gals. of enricher used per M cu. ft.	Water gas: Boiler fuel per M cu. ft. gas produced	Water gas: Generator fuel per M cu. ft. gas produced	Water gas: Tar produced per M cu. ft. gas produced	Water gas: Tar produced per M gals. oil used, gals.	Water gas: Av. selling price tar at works per gal.
Chippewa Falls	....	...	....	...	....	...	...	...	....	5.33	...	38.2	...	...	....
Watertown ...	3,447	4.95	1,193	416	$4.75	12.0	$0.03	...	....	...	...	...	...	...	....
Ashland	....	...	....	...	....	...	...	...	....	4.90	49.0	48.0	...	...	....
Beloit	....	...	....	...	....	...	...	...	....	3.45	14.9	38.1	0.30	88.2	$0.03
Eau Claire ...	4,597	5.12	1,476	397	6.22	12.9	0.045	...	....	...	...	...	...	...	....
Fond du Lac..	5,895	5.30	933	400	5.75	12.5	0.045	...	....	4.24	...	41.5	...	...	....
Janesville	....	...	....	...	....	...	...	...	....	4.11	16.8	39.5	0.12	30.2	....
Manitowoc ...	5,060	5.10	1,454	14	4.86	10.60	0.032	...	....	...	...	...	...	...	....
Marinette	1,983	4.20	1,190	205	5.30	12.00	0.03	...	....	...	...	...	...	...	....
Wausau	3,286	4.85	1,200	398	6.25	12.00	0.03	...	....	...	...	...	...	...	....
Appleton	7,647	5.19	1,358	359	6.08	13.16	0.03	2.42	0.057	3.53	15.0	39.4	...	...	....
Green Bay ...	7,658	4.90	....	1,300	4.57	11.00	0.031	...	....	...	...	...	...	...	....
Kenosha	....	...	....	...	....	....	...	...	....	3.70	26.0	83.0	3.00	0.1	0.035
Madison	....	...	....	...	....	....	...	...	....	3.58	13.0	37.0	0.35	60.0	0.01
Sheboygan ...	13,587	4.85	1,200	403	5.90	12.39	0.01	...	....	...	...	...	...	...	....
La Crosse	10,025	5.21	1,300	174	5.00	13.00	0.033	...	....	4.18	...	...	...	...	....
Oshkosh	10,808	5.22	1,300	328	5.94	12.50	0.028	2.83	0.075	...	...	...	...	...	....
Racine	50,155	4.75	1,374	357	4.48	12.70	0.035	3.00	0.085	...	...	...	...	...	....

TABLE XXVIII. OPERATING EXPENSES. CENTS PER M-CU-FT. SOLD

	M-cu. ft. sold	Production expense	Prod. ex. less residuals	Distribution expense	Commercial expense	General expense	Undistributed expense	Total, less residuals	Total	Tax expenses
Chippewa Falls	8,573	63.9	63.9	6.4	1.8	13.5	2.2	87.8	87.8	1.7
Watertown	29,430	79.2	54.5	3.7	4.8	10.7	7.0	105.4	80.7	5.0
Ashland	14,287	79.9	79.9	7.5	4.8	21.1	3.1	116.4	116.4	7.6
Beloit	69,835	39.6	38.3	11.7	2.0	11.4	1.4	66.1	64.8	6.5
Eau Claire	45,744	72.0	24.2	7.4	5.3	14.3	1.1	100.1	52.3	9.4
Fond du Lac	65,028	77.1	34.6	7.1	5.2	12.3	4.8	106.5	64.0	8.7
Janesville	69,914	45.7	45.4	7.8	14.8	6.6	1.3	76.2	75.9	9.3
Manitowoc	44,670	76.8	32.9	5.4	6.2	20.4	1.7	110.5	66.6	8.7
Marinette	12,739	97.0	54.0	7.2	10.1	7.1	5.4	126.8	83.8	5.5
Wausau	29,499	85.9	45.0	5.1	8.1	14.3	3.8	117.2	76.3	9.6
Appleton	87,138	68.4	33.3	10.2	4.3	9.9	5.4	98.2	63.1	7.5
Green Bay	63,181	76.2	35.5	13.6	6.7	14.4	3.3	114.2	73.5	6.0
Kenosha	135,146	25.9	25.8	6.8	4.9	3.7	2.4	43.7	43.6	4.5
Madison	195,829	40.9	40.4	11.8	5.5	7.7	...	65.9	65.4	4.3
Sheboygan	59,018	76.3	38.9	7.7	6.5	12.2	2.6	105.3	67.9	6.6
La Crosse	96,038	85.8	46.5	7.9	3.4	8.6	3.5	109.2	69.9	7.6
Oshkosh	107,702	69.8	32.9	4.6	2.4	15.8	4.0	95.5	59.6	8.5
Racine	274,014	79.3	17.3	5.0	5.9	5.9	3.3	99.4	37.4	6.9
Superior	88,140	42.8	42.8	8.6	4.8	4.9	0.1	61.2	61.2	3.8

TABLE XXIX

City	A	B	C	D	E
Works superintendence and labor	3.76	2.57	14.75	14.54	18.79
Boiler fuel	2.50	0.08	2.80	....	2.93
Water	0.07	0.14	0.22	0.13	....
Fuel under retorts	....	....	....	6.91	10.21
Coal carbonized	....	....	44.87	34.48	39.43
Coal gas enricher	....	....	0.44	....	....
Generator fuel	7.73	11.02	....	....	....
Water, gas, oil	14.17	17.30	....	0.08	....
Purification supplies	0.24	0.50	....	....	0.54
Miscellaneous works expense	0.50	0.31	3.89	0.73	3.02
Repairs, works and station structures	0.19	0.44	1.22	0.72	0.36
Repairs, power plant equipment	....	0.35	....	0.08	0.59
Repairs, gas apparatus	0.82	0.39	0.73	6.46	2.27
Repairs, works, tools	....	....	....	....	0.50
Gas storage	0.04	....	....	0.38	....
Gas from other sources	....	....	....	....	....
Residuals produced, Cr.	0.67		....	26.57	35.33
Total production expenses	29.35	33.09	68.91	37.94	43.30
Transmission pumping	0.02	0.76	....	0.20	....
Distribution super., supp., and exp.	0.48	0.35	3.93	1.19	3.16
Work on meters and consumers' premises	2.37	1.01	7.72	3.85	2.69
Repairs, gas mains and services	0.66	3.10	1.07	0.49	0.95
Repairs meters, tools and appliances	1.68	0.31	3.93	0.46	2.34
Total transmission and distribution exp.	5.21	5.53	16.65	6.19	9.13
Total municipal street lighting exp.	....	5.96	....		....
Total commercial expenses, gas	5.10	10.85	6.30	10.21	14.88
General administration	7.95	4.69	11.82	9.31	9.23
Insurance	0.37	0.36	2.31	1.20	1.63
Relief dept. and pensions	....	....	....	1.08	....
Franchise requirements	....	....	....	....	....
General amortization	6.14	4.69	16.71	4.11	....
Injuries to persons and property	....	....	0.08	1.08	0.34
General stationery and printing	0.28	....	0.52	0.14	0.66
Store and stable expenses	0.85	2.63	....	2.75	0.98
Cost of manufacturing residuals sold	....	....	....	17.66	....
Residuals and by-products expenses	....	....	....	6.05	....
Misc. adjustments, balance	cr. 0.17	cr. 2.18	cr. 3.38	....	3.75
Total general and misc. expenses	15.43	10.19	28.06	43.35	9.08
Total operating expenses	55.09	65.61	119.92	97.69	76.40

Wisconsin. Tables XXVI-XXVIII are compiled from data in the Report of Railroad Commission of Wisconsin, June 30, 1914.

New York. Table XXIX is abstracted from the annual report, the Public Service Commission of New York, 2nd District, for the year ending Dec. 31, 1915.

Table XXIX gives the itemized operating expenses of five gas companies in New York State. A and B manufacture water gas only; C, D and E coal gas only.

A is the Binghamton Gas Works, which had 82.3 miles of mains, 11,591 consumers meters in service, and sold 244,179 M ft. of gas out of 255,247 manufactured.

B is the Nassau and Suffolk Ltg. Co. which had 225.9 miles of mains, 5,525 meters in service, and sold 181,573 M out of 266,145 manufactured.

C is the Ogdensburg Gas Co., which had 12.3 miles of mains, 1,528 meters, and sold 24,005 M out of 27,923 manufactured.

D is the Canandaigua Gas-Light Co. which had 13.8 miles of mains, 2,358 meters, and sold 27,869 M out of 29,044 manufactured.

E is the Homer and Cortland Gas Light Co. which had 26.4 miles of mains, 2,299 meters, and sold 29,571 M out of 35,121 manufactured.

CHAPTER XVII

PUMPS AND PUMPING

The process of pumping is logically divisible into suction pumping and force pumping. In the former the pressure on the column of liquid is exerted by the atmosphere behind a vacuum generated by the pump, whereas in the latter the pump is doing all the pushing and no pulling.

Since the atmospheric pressure is equivalent to only about a 34 ft. column of water this is the theoretical limit of the suction or lift capacity of a pump. The practical limit is about 25 ft. with a first class plunger pump and considerably less than this with equipment of the centrifugal type.

It follows, therefore, since centrifugal pumps are extremely simple and inexpensive, that where it is convenient to place the pump below or near the level of the source of supply the economic advantages are likely to be in favor of the rotary type. In other cases the plunger type is generally more desirable.

Of late years, the air lift has come into quite general use and possesses some very striking advantages for special work, particularly in view of its cheapness in first cost and simplicity of operation, two practical advantages which are apt to offset a considerable deficit in theoretical efficiency. In comparing two different methods of pumping and then deciding on the type of equipment to be installed, it should be borne in mind that these costs are of various classes, some of which are very prominent in certain equipment in which others are inconsiderable, while with a radically different type these items may be reversed with sometimes startling effect upon the cost equation.

These items of cost may be figured on the basis of the following list by way of memorandum:

Annual cost:

1. Initial expense + installation × annual interest rate.
2. Initial expense + installation × annual depreciation rate.
3. Initial expense + installation × annual rate for repairs.
4. Labor cost of attention and operation.
5. Superintendence.
6. Overhead.
7. Annual cost for fuel oil and other supplies.
8. Or annual cost of purchased power.

The above annual costs, divided by the total amount of water pumped, will give the unit cost for the particular conditions involved. This should be worked out for each type of equipment, having regard to its particular efficiency, fuel cost, etc., before deciding upon the particular type for the work in hand.

Classification. Pumps may be classified in various ways, but for the consideration of their mechanical action Turneaure and Russell in Public Water Supplies state they may be best considered under the following heads:

1. Displacement-pumps.
2. Impeller-pumps.
3. Impulse-pumps.
4. Bucket-pumps.

The various subdivisions of the classification are shown in the diagram:

CLASSIFICATION OF PUMPS

- Pumps
  - Absolute volume displaced / Displacement
    - Reciprocating
      - Action
        - Double
        - Single
      - Class
        - Piston
        - Plunger
          - Inside-packed
          - Outside-packed
          - Center-packed
      - Type
        - Power
          - Single
          - Duplex
          - Triplex
        - Steam
          - Application
            - High-pressure
            - Compound
          - Arrangement
            - Direct-acting
            - Crank and flywheel
            - Compensator
        - Hydraulic
          - Direct-acting
          - Crank and fly wheel
      - Arrangement
        - Vertical
        - Horizontal
      - Use
        - Surface .suction)
        - Submerged or deep well
    - Rotary
    - Air-displacement / Steam-vacuum / Continuous-flow
      - Screw
      - Chain
      - U pump
      - Double-acting
  - Impeller / Continuous application through some mechanical agency or medium
    - Centrifugal
      - Impeller
        - Opened
        - Closed
      - Case
        - Side suction
        - Double suction
      - Arrangement
        - Horizontal
        - Vertical
    - Jet
      - Water
      - Steam
      - Air
  - Impulse (as name implies) — Water-ram. Humphrey gas pump.
  - Bucket (receptacle alternately filled and emptied)
    - Wheel
    - Band

Pump Prices hereinafter given are all net f.o.b. factory.

Centrifugal Pumps. The centrifugal pump has been developed and perfected during the past seven years, so that it is now recognized as a simple, reliable pump of great range.

TABLE I. IRON VERTICAL CENTRIFUGAL PUMPS

Discharge	H.p. required for each ft. elev.	Diam. and face of pulley (ins.)	Capacity per min. (gals.)	Floor space required, ft.	Shipping wt., (lbs.) Submerged type	Suction type	Price complete Submerged type	Suction type
1½	.058	5 x 6	70	2 :75	120	135	$20	$30
2	.10	7 x 8	120	3 :33	198	250	32	50
3	.22	7 x 8	260	3 :5	235	340	47	73
4	.30	8 x 10	470	4 :0	380	495	55	85
5	.45	10 x 10	735	4 :6	605	785	70	105
6	.59	12 x 12	1,050	4 :6	740	1,050	85	140
10	1.52	20 x 12	3,000	5 :4	1,430	1,925	165	275
12	2.00	24 x 14	4,200	6 :0	2,640	3,000	210	350
*12	2.00	20 x 12	4,200	3 :75	2,000	2,500	185	325
18	4.50	36 x 18	10,000	7 :0	6,000	7,000	470	790
*18	4.50	30 x 16	10,000	6 :5	2,900	3,300	420	710

* Refers to low-lift pumps for elevations up to 25 ft.

TABLE II. IRON HORIZONTAL CENTRIFUGAL PUMPS

Discharge	Suction	Capacity per min. (gals.)	H.p. for each ft. of elevation	Diam. and face of pulley (ins.)	Floor space (ins.)	Shipping wt. (lbs.)	Price
1½	2	70	.058	6 x 6	17 x 31	175	$22
2	3	120	.10	8 x 8	23 x 37	350	37
3	4	260	.22	8 x 8	25 x 39	415	55
4	5	470	.30	10 x 10	29 x 41	615	65
5	6	735	.45	12 x 12	34 x 54	940	82
6	8	1,050	.59	15 x 12	37 x 55	1,180	100
10	12	3,000	1.52	24 x 22	51 x 69	2,610	197
12	15	4,200	2.00	30 x 14	63 x 71	3,615	250
*12	12	4,200	2.00	20 x 12	51 x 59	2,800	250
18	20	10,000	4.50	40 x 16	93 x 103	9,000	650
*18	20	10,000	4.50	30 x 16	66 x 72	5,800	575
*24	24	15.000	6.50	48 x 20	90 x 98	10,800	1,075
24	24	15,000	6.50	48 x 36	94 x 137	13,000	1,500

* Low-lift pumps for elevations up to 25 ft.

The principal trouble with a centrifugal pump, especially when the pump is at a substantial height above the water, is in starting it. When the pump sucks it must be reprimed and started again. Therefore, if the amount of water to be handled is not as great as

the minimum capacity there will be many stops and knock-offs to prime. Before starting up a steam pump, especially in cold weather, it should be well warmed up by live steam from the end of a hose in order to thaw out any ice that may have formed in the cylinders and to give the iron parts a chance to expand gradually.

Iron Vertical Centrifugal Pumps, submerged or suction type, furnished complete with short shaft and coupling, one bearing, pulley for connecting shaft and discharge elbow, are used extensively for irrigation purposes, sewage pumping, and for any place where a pump may be placed in a pit. Suitable for elevating water 50 to 60 ft.

Iron Horizontal Centrifugal Pumps for belt drive. A pump used extensively for all purposes.

The above pump, fitted with a direct connected vertical steam engine costs: 4 in. side suction, 4x4 in. engine, $210; weight, 1,290 lbs. 5 in. side suction, 5x5 in. engine, $224; weight 1,440 lbs. 6 in. side suction, 6x6 in. engine, $238; weight 1,570 lbs.

Double Suction Iron Pumps, built extra heavy for elevating water to great heights.

TABLE III. DOUBLE SUCTION CENTRIFUGAL PUMPS

Discharge	Suction	Capacity per min. (gals.)	H.p. required for each ft. elevation	Diam and face of pulley (ins.)	Floor space (ins.)	Shipping wt. (lbs.)	Price
1½	2	70	.058	7 x 8	20 x 30	290	$30
2	3½	120	.10	8 x 8	26 x 35	510	45
3	3½	260	.22	8 x 8	27 x 38	615	67
4	5	470	.30	10 x 10	33 x 40	900	87
5	6	735	.45	12 x 12	37 x 49	1,530	125
6	7	1,050	.59	15 x 12	43 x 51	1,730	175
10	11	3,000	1.52	24 x 12	57 x 73	3,325	387
12	13	4,200	2.00	30 x 14	69 x 82	5,500	560
19	20	10,000	4.50	40 x 16	90 x 80	9,300	1,025

Direct Connected Dredging Pumps, complete with suction and discharge elbow, flap valve and steam primers, lubricator and oil cups. Cast iron impellor. The shipping weight and the price may vary 20% from the averages given in Table IV.

Belt Driven Sand and Dredging Pumps, complete except for pipe or hose, in Table V.

Pulsometer. A very well known steam operated vacuum pump consists of two bottle shaped cylinders with the necessary valve inlet and outlet pipes. The operation of this pump is sustained by alternate pressure and vacuum. Steam, cushioned by a layer of air automatically admitted, is brought to bear directly upon the liquid in the pump chambers and forces it out through the discharge pipe; the subsequent rapid condensation of the steam, ef-

TABLE IV. DIRECT CONNECTED DREDGING PUMPS

No. pump and diam. of suction and discharge	Total head	Engine description	Size of cylinders		Capacity, yds. per hr. (20% solids)	Largest diam. of solids (ins.)	Weight (lbs.)	Price
			Diam.	Stroke				
4	15	Single	5	5	30	2	1,600	$224
4	20	Single	6	6	30	2	1,800	240
4	25	Double	5	5	30	2	2,000	328
6	15	Single	6	6	60	4	2,500	285
6	20	Single	7	7	60	4	2,700	316
6	25	Double	6	6	60	4	3,000	415
8	15	Single	9	9	125	6	4,750	501
8	20	Double	7	7	125	6	5,800	567
8	25	Double	8	8	125	6	6,500	723
10	15	Single	10	10	200	8	7,500	645
10	20	Double	9	9	200	8	9,500	822
10	25	Double	10	10	200	8	10,500	1,000
12	15	Single	12	12	300	10	10,000	892
12	20	Double	10	10	300	10	12,800	1,069
12	25	Double	12	12	300	10	16,000	1,485

TABLE V. BELT DRIVEN PUMPS

No.	Diam. of suction and discharge	Capacity, yds. per hr. (20% solids)	H.p. required per 10 ft. head	Diam. and face of pulley, ins.	Shipping weight (lbs.)	Largest diam. of solids (ins.)	Price
4	4	30	4	12 x 12	1,200	2	$108
6	6	60	8	18 x 12	1,850	4½	155
8	8	125	15	24 x 12	3,600	6	245
10	10	200	25	30 x 14	4,550	8	310
12	12	300	30	40 x 16	8,000	10	435

fected by the peculiar construction of the pump, forms a vacuum in the working chambers, into which atmospheric pressure forces a fresh supply of liquid through the suction pipe. This action is maintained quite automatically, and is governed by a self-acting valve ball in the neck of the pump, which obeys the combined influences of steam pressure on one side and vacuum on the other. The valve ball oscillates from its seat in the entrance to one chamber to its seat in the entrance to the other chamber, thereby distributing the steam.

This pump will do all classes of rough service water raising up to 75 ft. elevation. It has no piston, no packing, no oil, and seldom breaks down, but is very uneconomical of steam.

Each pump is furnished complete with either basket or mushroom strained steam and release valve connection, and pump hook for suspending when necessary, but no piping.

Another pump working on similar principles, but which may be slightly more economical in steam consumption and works against greater heads, the main differences are in the steam distribution, which, in this type, is governed by a simple engine, and in the necessity of oil for lubrication. These pumps will work, admitting 30% of air or 25% of grit, and a continuous run of four months has been recorded. They are especially valuable in quicksand and wherever the quantity of water is variable. The cost of repairs is nominal.

TABLE VI. PULSOMETER PUMPS

Size of pipe (ins.)			Capacity in gals. per min. at different elevations and boiler h.p.				Price, f.o.b. New York		
Steam	Suction	Discharge	25 ft.	50 ft.	75 ft.	H.p.	Flat valve (standard)	Ball valve (special)	Weight (lbs.)
¼	1½	1½	20	17	13	4	$68	$71	95
⅜	2	2	60	50	38	5	90	95	140
½	2½	2½	100	80	65	6	135	142	295
½	3	3	180	160	115	9	158	168	430
¾	3½	3½	300	265	200	12	203	217	570
¾	4	4	425	375	275	15	248	270	745
1	5	5	700	625	450	25	360	396	1,375
1½	11	6	1,000	900	650	35	450	495	2,100
2	8	8	2,000	1,800	1,400	70	900	...	3,800

These pumps are made in two types; the standard consists of two vertical cylinders, each with a discharge and suction valve, topped by one simple, 3-cylinder horizontal engine, with the necessary air cocks, lubricator and condenser piping, but no steam, suction or discharge pipe is supplied.

The Junior consists of a single cylinder, a steam piston valve, suction valve, discharge valve, condenser pipe, check valve and stop cock, and is furnished with patented foot valve and quick cleaning strainer.

Cat. No.	Size of pipes (ins.) Steam.	Suction.	Dis'ge.	Capacity in gals. per minute.	Greatest dimensions. Br'dth.	H'ght.	Weight, Lbs.	Price.
A	½	3	2½	100	14½	47	219	$100
B	¾	4	3	150	17½	47	290	125
C	¾	5	4	200	21	47	410	175

Capacities stated in table in gallons per minute and per hour are calculated on a head or lift of 20 ft. These capacities diminish at the rate of about 6% for each 10 ft. of additional head up to 100 ft., the highest lift.

A Double Acting Force Hand Pump for filling tank wagons from brooks or other water sources has a capacity, with one man pumping, of one to two barrels per minute. Maximum total lift and force, 50 ft.; maximum lift 25 ft., cylinder diameter 5 ins.,

stroke, 5 ins. capacity per stroke 0.85 gal. Suction hose 2 ins., discharge hose 1 in.; price of pump, with strainer, hose-couplings and clamps, but no hose, $8.

Lift and Force Diaphragm Pump, No. 3, one man pumping, capacity, 4,000 gals. per hour; price, with 15 ft. of hose, $42; with 20 ft. of hose, $48. No 4, two men pumping, capacity 6,000 gals. per hour; price, with 15 ft. of hose, $61.50, with 20 ft. of hose, $70. Diaphragm pumps are suited for general construction work, where the pumping is intermittent and the amount of water to be raised is small. The life of the pump depends on the care it is given and the amount of grit the water contains. In very gritty water a diaphragm wears out in two or three weeks. These cost $1.30 each; extra strainers, which are sometimes broken by careless handling, cost $1.35 each. A set of brass hose-couplings costs $3.

Lift and Force Diaphragm Pump, No. 6, capacity 1,000 gals. per hour with one man working; weight 50 lbs.; price, with 10 feet of suction and 25 ft. of connection hose, $54. No. 8, 4,000 gals. per hour with two men pumping; weight 270 lbs.; price $104.50. No. 10, 6,000 gals. per hour with two mem pumping; weight, 395 lbs.; price $139.75. Pumps alone, No. 6, $25; No. 8, $70; No. 10, $90. Pumps, with 20 ft. of suction hose and 200 ft. of connection hose, No. 6, $123.50; No. 8, $200; No. 10, $276.

The above pumps are especially suitable in mining prospecting or for any work where the water contains as much as 50 per cent. of solids. These pumps will handle grout and quicksand.

A Diaphragm Pump, known as No. 3 Contractors' Mud Pump, with double diaphragms, and a gasoline engine rated at 3 h.p., and having a speed of 500, all mounted on a truck, equipped with 15 ft. of 3 in. spiral wire suction hose and 25 feet of discharge hose, with brass couplings and strainer, tools, etc., costs $300. The capacity of this pump is from 6,000 to 8,000 gals. per hr. of water containing a considerable amount of sand, sewage and gravel. It is guaranteed for one year; weight, 1,000 lbs.; space occupied 2 ft. by 5 ft.

Suction or Bilge Pump, consisting of a tin pipe with a plunger worked by hand.

Diam. ins.	Price per lin. ft.
2	$0.45
2½	.50
3	.55
3½	.60
4	.65

Pumps less than 5 ft. long charged as 5 ft.

Special Pump. In the Marsh steam pump, the steam valve is made of brass, and though nicely fitted, moves freely in the central bore of the steam chest. It has no mechanical connections with other moving parts of the pump, but is actuated to admit, cut off and release the steam by live steam currents, which alternate with the reciprocations of the piston. Each end of the valve is made to fit the enlarged bore of the steam chest, and it is due to those enlarged valve heads, which present differential areas to the action

of steam, and the perfect freedom of the valve to move without hindrance from other mechanical arrangements or parts, that the flow of steam into the pump is automatically regulated. Because the pump is so regulated it can never run too fast to take suction; or, should the water supply give out when the throttle valve is wide open, no injury can occur to the moving parts. The steam valve does not require setting. The steam piston is double, and each head is provided with a metal packing ring, the interior space constituting a reservoir for live steam pressure, supplied by the live steam pipe through a drilled hole. At each end of the steam cylinder are similar holes leading to each end of the steam chest, which, together with the centrally drilled hole and the space between the piston heads, constitute positive means for tripping or reversing the valve with live steam.

TABLE VII. COST AND WEIGHT OF MARSH STEAM PUMPS

Size	Gallons per hour.	Horse-power.	Floor space, ins.	Weight, lbs.	Price
B	200	36	7 x 12	40	$11.50
BB	400	60	8 x 16	75	14.00
C	500	75	10 x 22	145	25.00

TABLE VIII. SIMPLEX PISTON PUMPS FOR TANK AND LIGHT SERVICE

Diam. steam cylinders, ins.	Diam. water cylinders, ins.	Stroke, ins.	Weight, lbs.	Price, f.o.b., factory
3	3	3	125	$33
3¾	3¼	6	260	50
4	4	5	300	56
4	5	5	370	62
4	5	6	420	68
5	4	6	420	68
5	5	6	490	74
5½	6½	8	780	100
6½	6½	8	890	115
8	8	10	1,400	168
8	9	10	1,500	180
8	8	12	1,600	190
8	9	12	1,750	200
8	10	12	2,000	230
8	12	12	2,650	300

These pumps are furnished with bed-plate, outboard bearing and gears ready to receive motor, all in accordance with the requirements for the construction of fire pumps of the Underwriters Association. Thirty h.p. for each fire-stream will drive these pumps against 100 lbs. pressure.

For elevations of 250 to 2,000 feet — 110 to 865 lbs. pressure long stroke,— single-acting Triplex Plunger Pump for heavy duty. The prices given are for regular construction which provides — iron plungers, cylinders and glands and rubber disc valves reinforced with bronze plates working on bronze guides and seats. Air chambers are furnished on sizes 10x14 in. and larger.

TABLE IX. SIMPLEX PISTON PUMPS, BOILER FEED PUMPS OR HEAVY SERVICE

Diam. steam cylinders, ins.	Diam. water cylinders, ins.	Stroke, ins.	Weight, lbs.	Price, f.o.b., factory
5	3	6	360	$61
7	5	10	930	118
10	6	12	1,650	194
12	7	12	2,150	247
12	7	16	2,650	290
14	8	12	2,650	290
14	8	14	3,000	325
14	9	16	3,500	370
16	9	16	4,000	410
18	12	16	5,100	500
20	14	16	6,000	590
20	12	24	7,400	710

TABLE X. DUPLEX PISTON PUMPS FOR TANK OR LIGHT SERVICE

Diam. steam cylinders, ins.	Diam. water cylinders, ins.	Stroke, ins.	Weight, lbs.	Price, f.o.b., factory
3	2¾	3	125	$34
4½	3¾	4	310	56
5¼	4¾	5	650	90
6	5¾	6	700	95
6	7½	6	860	112
6	8½	6	980	125
7½	7½	6	1,000	125
7½	8½	6	1,100	137
7½	6	10	1,250	155
7½	8½	10	1,600	195
8	8	10	1,600	195
9	8½	10	2,200	250
10	12	12	4,400	450
10	14	12	4,700	470
10	16	12	5,000	500

TABLE XI. DUPLEX PISTON PUMPS, BOILER FEED PUMPS OR HEAVY SERVICE

Diam. steam cylinders, ins.	Diam. water cylinders, ins.	Stroke, ins.	Weight, lbs.	Price, f.o.b., factory
2	1¼	2¾	90	$29
3	2	3	100	30
3½	2¼	4	165	40
4½	2¾	4	265	50
5¼	3½	5	410	66
6	4	6	560	78
7½	5	6	780	100
7½	4½	10	1,100	140
8	5	10	1,220	155
8	6	10	1,350	162
9	5	10	1,400	168
10	6	10	1,650	195
10	6	12	2,700	300
12	7	12	4,100	420
14	8½	12	4,600	460

TABLE XII. DUPLEX PLUNGER PUMPS, CENTER PACKED TYPE FOR BOILER FEED AND HEAVY SERVICE

Diam. steam cylinders, ins.	Diam. water cylinders, ins.	Stroke, ins.	Weight, lbs.	Price, f.o.b., factory
4½	2¾	4	530	$79
5¼	3½	5	680	95
6	4	6	840	110
7½	5	6	1,100	132
7½	4½	10	1,600	176
8	5	10	1,750	189
8	6	10	1,950	205
9	5	10	2,100	215
10	6	10	2,600	255
12	7	10	3,800	340
12	8½	10	4,200	370
14	8½	10	5,100	440
10	6	12	3,200	300
12	7	12	4,500	390
14	8½	12	6,200	510
*14	7¼	12	5,700	480
*16	9	12	7,600	610
*18	10	12	9,200	720
*20	12	16	16,000	1,150

* Underwriters' fire pumps.

TABLE XIII. AUTOMATIC DUPLEX PISTON FEED PUMPS AND RECEIVERS

Diam. steam cylinders, ins.	Diam. water cylinders, ins.	Stroke, ins.	Weight, lbs.	Price, f.o.b., factory
3	2	3	400	$84
4½	2¾	4	550	94
5¼	3½	5	950	118
6	4	6	1,150	138
7½	5	6	1,250	147
7½	4½	10	1,650	194
8	5	10	1,750	210

For 150 lbs. water pressure.

TABLE XIV. AUTOMATIC DUPLEX PLUNGER FEED PUMPS AND RECEIVERS*

Diam. steam cylinders, ins.	Diam. water cylinders, ins.	Stroke, ins.	Weight, lbs.	Price, f.o.b., factory
4½	2¾	4	700	$125
5¼	3½	5	1,200	138
6	4	6	1,450	164
7½	5	6	1,550	178
8	5	10	2,150	430

* For 200 lbs. water pressure.

TABLE XV. UNDERWRITERS' ROTARY FIRE PUMP

Capacity per min., gals.	Stand. 250 gal. fire str'ms.	R.p.m.	Suct. disc. pipe, ins.	Disc. hose	Price f.o.b. factory, (30 days; 20% 10 days)
500	2	275	6	2½	$750
1,000	4	245	8	2½	$1,450

TABLE XVI. DOUBLE-GEARED TRIPLEX PUMPS

Diam., ins. stroke 14 ins.	Gals. per revolution of crank shaft	Working pressure, lbs.	Suct. pipe, ins.	Disc. pipe, ins.	Price f. o. b. factory
5	3.57	865	6	5	$2,100
6	5.14	605	6	5	2,025
7	7.00	435	7	6	1,985
8	9.13	345	7	6	1,970
10	14.28	215	8	8	1,910
11	17.28	175	12	10	1,875
12	20.56	150	12	10	1,875
13	24.12	130	12	10	1,910
14	27.98	110	12	10	1,950

Gear ratio 5 to 1. Double belt,— pulley 60 by 14 ins. Customary speed 40 r.p.m. of crank shaft.

Formulæ for the Cost of Pumps. In Tables XVII to XIX are given formulæ for the cost boiler feed pumps, centrifugal pumps and geared power pumps. These formulæ were developed by A. A. Potter in Power, Dec. 30, 1913.

TABLE XVII. BOILER FEED PUMPS

(After Potter).

Type	Capacity gals. per hr.	Cost in $ equals gals. per hr. multiplied by
Single-cylinder, piston pattern	Up to 6,000	(17.8 + 0.2586)
Single-cylinder, piston pattern	6,000 to 27,000	(106.8 + 0.011045)
Duplex, piston pattern	Up to 29,000	(585 + 0.0115)
Single-cylinder, outside-packed, plunger	Up to 24,000	0.034
Duplex outside-packed plunger pattern	Up to 49,000	0.042125

TABLE XVIII. CENTRIFUGAL PUMPS

(After Potter).

Type	Capacity gals. per min.	Cost in $ equals gals. per min. multiplied by
Horizontal, low pressure, single-stage	Up to 5,000	(52 + 0.05525)
Horizontal, high pressure, single-stage	Up to 5,000	(61 + 0.0868)
Horizontal, high pressure, single-stage	5,000 to 20,000	(210. + 0.0567)
Horizontal, high pressure, multi-stage	Up to 2,200	(117. + 0.233)
Vertical, low pressure, single-stage	Up to 20,000	(60. + 0.05575)
Vertical, high pressure, single-stage	Up to 20,000	(50. + 0.0865)
Vertical, high pressure, multi-stage	Up to 1,100	(125.7 + 0.27)

TABLE XIX. GEARED POWER PUMPS. (After Potter.)

Type	Capacity gals. per hr.	Cost in $ equals gals. per hr. multiplied by
Single cylinder	Up to 20,000	(90 + 0.0316)
Single-acting, triplex	Up to 83,000	(56 + 0.03867)
Double-acting, triplex	Up to 89,000	(195 + 0.0148)
Rotary force pumps	1,200 to 20,000	(8 + 0.0117)
Wet vacuum pumps	Up to 13,000	(18 + 0.01435)
Wet vacuum pumps	13,000 to 50,000	(14 + 0.00863)

TABLE XX. PUMPS FOR MINING AND HEAVY DUTY

(Duplex, compound, with semi-rotary steam valves and outside end packed plunger water end).

Size of pumps:	
Diam. high pressure steam cylinder, ins.	30
Diam. low pressure steam cylinder, ins.	50
Diam. of plungers, ins.	14
Length of stroke, ins.	48
Theoretical discharge:	
Gallons per stroke	31
Gallons per minute	2,325 to 3,100
Corresponding to strokes per minute	75 to 100
Floor space required, ft.	45 × 16
Shipping weight, lbs.	170,000
Cost f. o. b. cars, factory	$10,500
Cost of erection on foundation, but not including foundation	$450 to $500

Cost of attendance.— Three men working in 8 hr. shifts at from $1.65 to $2.40 per day each. (Wages would vary with location.)

Average fuel consumption with pump running condensing is 35 lbs. of steam per h.p.-hr.

Miscellaneous cost, oil, waste, etc., approximately $350 per annum.

TABLE XXI. COMPOUND HEAVY DUTY PISTON PUMPS

Size of pump:			
Diam. high press. steam cyl., ins.	14	18	24
Diam. low press. steam cyl., ins.	20	26	36
Diam. water cylinder, ins.	10	14	18
Length of stroke, ins.	16	20	20
Diam. of pump openings:			
Steam, ins.	2	2½	3
Exhaust, ins.	3½	5	6
Suction, ins.	8	10	12
Discharge, ins.	6	8	10
Theoretical discharge in gals.:			
Displacement per stroke	5.44	13.324	22.024
Per minute 100 ft. piston speed	408	800	1,322
Per hour 100 ft. piston speed	24,480	48,000	79,314
Water pressure against which pump will deliver water at full speed with 100 lbs. steam pressure at the throttle	150	130	140
Approximate dimensions:			
Length, ins.	130	155	165
Width, ins.	25	32	42
Height, ins.	72	95	105
Cost, net f. o. b. factory	$700	$1,100	$1,900

These pumps are designed for a maximum pressure of 150 lbs. per sq. in. in the water end.

TABLE XXII. DOUBLE-ACTING OUTSIDE-CENTER PACKED PLUNGER PUMPS

Size of pump:			
Diam. of steam cylinder, ins....	16	20	26
Diam. of water cylinder, ins....	10	14	18
Length of stroke, ins.	16	20	24
Diam. of pump openings:			
Steam, ins.	2	2½	3
Exhaust, ins.	2½	3½	5
Suction, ins.	8	10	12
Discharge, ins.	6	8	10
Theoretical discharge in galls.			
Displacement per stroke	5.44	13.22	22.42
Per minute at 75 ft. piston speed	306	600	991.5
Per hour at 75 ft. piston speed..	18,360	36,000	59,490
* Horse power of boiler pump will feed at 30 strokes per min.	2,200	5,375	10,575
Approximate dimensions:			
Length, ins.	130	160	185
Width, ins.	22	30	45
Height, ins.	65	80	100
Cost, net f. o. b. factory........	$575	$1,100	$1,800

* In this computation a slippage of 10% has been allowed.

These pumps are designed primarily for boiler feed service but are equally well adapted for general service. The water end is designed for a pressure of 180 lbs. per sq. in.

TABLE XXIII. HYDRAULIC RAMS

Size of drive pipe, ins.	Gallons per min. required to operate ram	Weight, lbs.	Price*
1¼	2– 6	150	$35.00
1½	6– 12	175	38.50
2	8– 18	225	42.00
2½	12– 28	250	46.00
3	20– 40	275	52.50
4	30– 75	600	105.00
6	75–150	1,200	192.50
8	150–300	2,200	350.00
12	375–700	3,000	525.00

* Prices given above are for single-acting rams; double-acting rams cost from 10–20% more than those listed, the smaller sizes costing proportionally more.

The prices given are net prices f. o. b. factory. For a successful installation the ram should be supplied with a liberal quantity of water under at least a 3 ft. head. The size of delivery pipe depends upon the installation but in general its diameter would be about one-half as large as the drive pipe.

Cost of Pumping in Water Works Steam Pumping Stations. A valuable discussion, with data, on the cost of pumping water in steam plants was presented in a paper by Kenneth F. Lees before

the 1913 annual convention of the Connecticut Society of Civil Engineers.

The cost of pumping water is best considered under the following headings, which will be discussed in the order given: 1, Losses in pumping. 2. Duty of pumping plants. 3. Cost of pumping equipment. 4. Cost of pumping, as shown by calculation, for plants of varying capacity and type. 5. Cost of pumping, as shown by results of actual practice.

The losses in pumping may be divided into four general headings: 1. Losses of generation. 2. Losses of conversion. 3. Losses in transmission. 4. Losses in application.

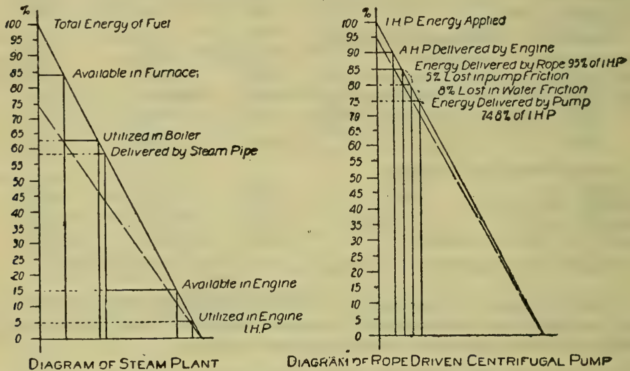


Fig. 1. Diagram of steam plant. Diagram of rope driven centrifugal pump.

Each of these general headings may be subdivided as shown. As an illustration of the value these losses assume in practice, Fig. 1 gives the efficiency diagrams as reported by Mr. Meade for the Rockford pumping plant, using a rope-driven centrifugal pump. In the diagram for the steam plant the length of the ordinate represents the total energy of the fuel. Of this 48% was found to be available in the furnace, while of this latter energy only 75% was utilized by the boiler, which is equivalent to about 63% of the total energy of the fuel. There was a drop of 4% in the steam pipe, a further drop of 15% as energy available in the engine, while of the total energy in the fuel only 5% was found to have been utilized as indicated horsepower.

In the diagram for the pump this indicated horsepower is laid off on a 100% scale, and the various losses from the engine to the pump are shown, the energy delivered by the pump having been found to be but 74.8% of the i.h.p. of the engine. This is equivalent to about 3.75% of the total energy of the fuel, and illustrates well the necessity for the reduction of losses to a minimum that pumping may be done economically.

Duty represents the ratio of work done to the energy expended in doing it. The terms usually used to express duty of pumping engines are foot pounds duty per 100 lbs. of coal, per 1,000 lbs. of steam, or per 1,000,000 heat units.

PUMPING LOSSES (Mead).

Generation. Losses in Pumping.

Generation	Fuel	Internal combustion engine gas, oil	Engine losses
		Steam	Furnace Boiler Piping
	Water power	Direct [ram] Indirect [wheels]	Ram losses Velocity losses Wheel losses
	Minor sources	Electric [primary batteries] Wind [mills] Waves [motors] Sun heat [solar engines]	Various mechanical and other losses due to method used

Conversion. Losses in Pumping.

Conversion	Internal combustion engine	Included in engine losses
	Steam	Engine and connection losses
	Electrical	Dynamo losses
	Hydraulic	Pump losses
	Pneumatic	Compressor losses

Transmission. Losses in Pumping.

Transmission	Mechanical	Direct connected shaft belt, rope, chain, gear, combinations	Various losses due to method used
	Hydraulic		Pipe friction Motor losses Connections
	Electrical		Transformer losses Wire losses Motor losses Connections
	Pneumatic		Pipe friction Air cooling Motor losses Connections

Application. Losses in Pumping.

Application	Pumping	Inlet pipe	Influx Velocity Friction
		Pump	Friction in valves and water passages Mechanical friction
		Discharge pipe	Pipe friction
	Ram		Pipe losses
	Steam		Radiation Condensation Pipe losses
	Air		Air pipe losses

Duty based on coal is very indefinite, since the heat value of coal varies greatly, and should be used only where the entire plant is considered and when the class of coal is also specified.

Duty based on steam is more definite, but still not exact. Steam has a greater value at high than at low pressures. Entrained water from the boiler and condensation in the pipes also cause a

TABLE XXIV. DUTY, CORRESPONDING COAL PER HORSE POWER HOUR AND COAL REQUIRED TO RAISE 1,000,000 GALS. 100 FT. HIGH

Duty in million ft.-lbs.	Pounds of coal per h.p. per hr.	Pounds of coal per million gals. 1000 ft. high
1	19.8	83,398
10	19.8	8,340
20	9.9	4,170
30	6.6	2,780
40	4.95	2,085
50	3.96	1,668
60	3.3	1,389
70	2.83	1,191
80	2.47	1,042
90	2.2	926
100	1.98	834
110	1.8	758
120	1.65	695
130	1.52	641
140	1.41	595
150	1.32	556
160	1.24	511

TABLE XXV. COMPOUND CONDENSING LOW DUTY PUMPING ENGINES

1,000,000 gals. per 24 hrs.	Pumping machinery, foundations and piping	Boilers, setting, piping and appurtenances	Total cost
3	$ 6,900	$ 3,000	$ 9,900
4	9,200	3,500	12,700
5	11,500	4,000	15,500
6	13,800	5,000	18.800
7	16,100	5,500	21,600
8	18,400	6,000	24,400
10	23,000	7,500	30,500
12	27,600	8,000	35,600
15	34,500	10,000	44,500
Triple condensing low duty pumping engines.			
3	$ 8,400	$2,000	$10,400
4	11,200	2,400	13,700
5	14,000	3,000	17,000
6	16,800	3,500	20,300
Compound condensing high duty pumping engines.			
5	$16,500	$2,000	$18,500
6	19,800	2,500	22,300
7	23,100	3,000	26,100
8	26,400	3,500	29,900
10	33,000	4,000	37,000
12	39,600	5,000	44,600
15	49,500	6,000	55,500

Triple condensing high duty pumping engines.

6	$ 28,800	$2,000	$ 30,800
7	33,600	2,500	36,100
8	38,400	2,500	40,900
10	48,000	3,000	51,000
12	57,600	3,500	61,100
15	72,000	4,000	76,000
20	96,000	5,500	101,500
25	120,000	7,000	127,000
30	144,000	8,000	152,000

TABLE XXVI. OPERATING COST OF COMPOUND CONDENSING LOW DUTY PUMPING ENGINE

Capacity of pumping engine per 24 hrs. in U. S. gal.	Cost of coal per year of 365 days.	Maintenance sinking fund, oil, waste, packing, etc.	Wages per year.	Maintenance, interest, sinking fund, of boilers.	Cost of pumping per 1,000,000 gals.
3,000,000	$ 4,687	$ 897	$3,600	$ 420	$13.15
4,000,000	5,672	1,196	3,600	490	11.26
5,000,000	6,504	1,495	3,600	560	9.99
6,000,000	7,807	1,794	3,600	700	9.52
7,000,000	8,410	2,093	3,600	770	8.93
8,000,000	9,600	2,392	3,600	840	8.44
10,000,000	11,913	2,990	3,600	1,050	8.07
12,000,000	13,320	3,588	4,800	1,120	7.81
15,000,000	16,784	4,485	4,800	1,450	7.75
Operating cost of triple condensing low duty pumping engine.					
3,000,000	$3,118	$1,092	$3,600	$280	$11.08
4,000,000	3,907	1,456	3,600	350	9.57
5,000,000	4,590	1,820	3,600	420	8.57
6,000,000	5,203	2,184	3,600	490	7.85
Operating cost of compound condensing high duty pumping engine.					
5,000,000	$3,556	$2,145	$3,600	$280	$7.85
6,000,000	4,161	2,574	3,600	350	7.31
7,000,000	4,800	3,003	3,600	420	6.94
8,000,000	5,379	3,432	3,600	490	6.62
10,000,000	6,550	4,290	3,600	560	6.19
12,000,000	7,665	5,148	3,600	700	5.86
15,000,000	9,355	6,435	3,600	840	5.75
Operating cost of triple condensing high duty pumping engine.					
6,000,000	$3,285	$3,168	$3,600	$280	$7.07
7,000,000	3,766	3,696	3,600	350	6.70
8,000,000	4,161	4,224	3,600	350	6.33
10,000,000	5,028	5,280	3,600	420	5.91
12,000,000	6,025	6,336	3,600	490	5.64
15,000,000	7,096	7,920	3,600	560	5.45
20,000,000	9,180	10,560	4,800	770	5.22
25,000,000	11,142	13,200	4,800	980	4.95
30,000,000	12,999	15,840	6,000	1,120	4.92

variation in results. Hence in considering duty with respect to steam the terms dry steam and a specified pressure should be included.

Duty in terms of B. t. u. is absolutely definite.

Low duty in a pumping plant means high coal and steam consumption for a given output, and thus increased cost for boilers. High duty means lower cost for boilers and fuel and increased cost of machinery. The next table gives the relation between duty, the corresponding coal per horsepower per hour, and the weight of coal required to raise 1,000,000 gals. 100 ft. high.

To summarize, then, we have in favor of high duty: 1. Maintenance account for boilers. 2. Interest on boilers. 3. Sinking fund for boilers. 4. The coal account.

Against high duty we have: 1. Maintenance account for machinery. 2. Interest on machinery. 3. Sinking fund for machinery. 4. Oil, waste, packing, etc. It is evident, therefore, that in every plant the layout question of duty must be considered in determining probable cost of pumping.

The above relations are shown in the following tables by Charles A. Hague, relating to initial and operating costs of plants with various types and classes of pumping engines, adequate boilers and fittings, the data are such as will show the prevailing conditions in the average run of plants in waterworks service. While it is, of course, safer to consider each particular case by itself, the tables will indicate closely approximate results. The data for the tables follow:

Number of days for year's work	365
Number of hours of pumping per day	16
Number of shifts per day	2
Length of shifts, hours	8
Pay of operating engineers per year	$1,200
Pay of firemen per year	600
Pay of extra men per year	600
Maintenance account of engines	3%
Sinking fund for vertical triple expansion engines	3%
Sinking fund for all other types of engines	5%
Maintenance account for boilers	4%
Oil, waste, packing and small repairs	1%
Coal, per ton of 2,000 lbs.	$3.00

The calculations for cost are based on a fair average price for machinery, foundations and appurtenances, together with boilers and their appliances. Also upon an actual evaporation in the boilers of 8 lb. of steam produced at working pressure per pound of coal.

Price of coal $3 per net ton of 2,000 lb. in the fire room ready for firing, and upon a water load on the plungers of 90 lb. per sq. in., which is equivalent to a head of 207 ft., including suction and friction of water. The tables are self-explanatory.

In considering the cost of pumping, as shown by results of actual practice, tables compiled by Mr. Sando some years ago (1902) give a fair idea of the expenses involved in large plants throughout the country, and the division of these expenses. The results of tests on more modern plants that have been recently reported, and of

which many have been consulted not only for steam, but also for oil, gas and electric plants, conform fairly well with them. See Tables XXVII and XXVIII.

TABLE XXVII. ACTUAL COST OF PUMPING IN VARIOUS CITIES

	Average quantity pumped in 24 hrs. Mil. gallons.	Average head pumped against, feet.	Average cost of coal in bins, ton of 2,240 lbs.	Division of total pumping expenses. Labor per cent.	Fuel, repairs and supplies per cent.	Pump horse power. Cost of a 24 hr. Based on total pumping expenses.	Based on cost of fuel only.	Cost of coal for a 24 hr. pump horse power at $1 per ton of 2,240 lbs.
Philadelphia	320.0	205.0	$3.38	34	66	$100.36	$53.27	$15.77
Baltimore	24.26	177.3	3.46	..	..	64.97	46.75	13.51
Boston	115.07	71.23	5.07	44	56	73.34	32.26	6.36
Pittsburgh	60.4	256.0	0.986	44	56	49.06	17.29	17.52
Cincinnati	55.58	248.6	1.39	43	57	139.74	36.10	25.97
Buffalo	114.0	147.73	1.86	39	61	76.76	25.64	13.82
St. Louis	135.8	154.2	1.50	40	60	65.71	25.99	17.32
Milwaukee	29.76	145.47	3.30	59	41	77.73	25.17	7.62
Cleveland	73.72	205.1	1.48	48	52	51.40	19.19	12.59
Providence	13.26	171.6	5.18	35	65	86.51	36.84	7.11
Brooklyn Borough	173.4	107.4	3.15	42	58	161.60	52.44	16.65
Manhattan Borough	52.77	111.55	5.25	48	52	128.46	66.63	12.69
Chicago	358.1	102.4	2.85	35	65	101.43	40.17	14.24

Consideration of the foregoing tables, both those with theoretical and actual results, show a great variation in the cost of pumping with location of plant, equipment of plant and with management. It is therefore difficult to come to any definite conclusion as to the cost of 1,000,000 ft.-gals. However, we may take as an average value, representing general practice, a cost of 4½ cts. to pump that quantity of water.

Cost of Complete Pumping Engines. Charles A. Hague, in the Transactions American Society of Civil Engineers, Dec. 1911, gives the following data:

Cost of pumping engines complete, with foundations, piping and appurtenances, per million gallons per 24 hrs. capacity.

1. Compound-condensing, low-duty engines, horizontal......$2,300
2. Low-duty triple, condensing, horizontal 2,800
3. Cross-compound, condensing, horizontal 3,300
4. High-duty triple, condensing, vertical 4,800

The first and second are non-rotative or "direct acting" machinery, and the third and fourth are of the crank-and-fly-wheel

TABLE XXVIII. ACTUAL COST OF PUMPING IN VARIOUS CITIES

Station	Million gals., 24 hrs.	Head, ft.	Expense per mil, gals., per ft.	Coal per long ton	Expense per mil. gals. per ft., coal at $1	Kind of fuel
			Cts.	$	Cts.	
Philadelphia:						
Queen Lane	71.2	274.9	3.64	3.683	0.988	Bituminous and small anthracite
Spring Garden	140.37	156.1	4.46	3.123	1.427	sizes.
Baltimore:						
Mt. Royal	14.4	170.75	2.97	3.39	0.875	Bituminous.
Boston:						
Chestnut Hill H. S.	29.85	128.0	3.2	4.72	0.67	Bituminous.
Chestnut Hill, L. S.	76.55	42.48	3.2	5.2	0.615	mixed with anthracite
Spot Pond	7.97	133.0	3.6	5.19	0.693	screenings.
Pittsburgh:						
Brilliant	53.3	268.0	1.64	0.986	1.663	Bit. and Pittsburgh nut and slack.
Buffalo	114.0	147.73	3.68	1.854	1.984	B. & A. screenings.
St. Louis:						
Chain of Rocks, L. S.	68.62	57.75	4.0	1.50	2.666	
Baden, H. S.	35.42	300.0	1.93	1.50	1.284	Illinois bituminous.
Bissel's Pt., H. S.	31.78	200.0	4.66	1.50	3.106	
Milwaukee:						
North Pt.	24.06	156.77	3.16	3.302	0.956	Bituminous screenings
High Service	5.69	97.69	7.53	3.302	2.28	Fairmount.
Cleveland:						
Division St.	69.96	205.1	2.6	1.48	1.645	Youghiogheny and saline slack.
Providence:						
Pettaconsett	11.84	171.6	3.78	5.18	0.729	B. & A. egg size.
Brooklyn, N. Y.:						
Ridgewood, Old	40.56	173.2	6.36	3.02	2.105	
Ridgewood, New	40.33	169.1	4.85	2.54	1.909	Anthracite egg size.
Milburn	39.16	53.6	6.7	3.72	1.801	
Manhattan:						
179th St.	30.4	129.43	5.06	5.09	0.994	
High Bridge	1.93	114.35	16.30	5.35	3.046	Anthracite egg size.
98th St.	20.46	89.7	8.31	5.30	1.567	
Chicago:						
Springfield Ave.	38.73	98.2	3.7	2.89	1.241	
14th St.	70.09	110.8	3.35	3.17	1.056	Bituminous.

type. The figures do not include anything for buildings, land, chimneys, wells, boilers, etc.

The cost of boilers with mechanical stokers, feed-pumps and appurtenances, steam piping, and minor details — everything ready for service under average conditions — would be covered by $20 per boiler h.p.

It is impossible to include all plants, therefore these averages are based on:

Total water load against the plungers, 90 lbs. per sq. in., or a head of 207 ft. including suction and friction.

Actual evaporation in the boilers under working conditions, 8 lbs. of water per pound of coal, with feed at 150 degs. and with coal at $3 per net ton of 2,000 lbs.

Steam pressure at throttle valve of engine, 75 lb. gauge, for low-duty compound; 125 lb. gauge, for low-duty triple and cross-compound; 150 lb. gauge, for high-duty triple; an allowance of 5 lb. above the pressures given for boiler pressures.

The desire is often expressed for a schedule, rate of cost, or price of pumping engines, but it is a very difficult matter to make a price list at any certain time, which will be reliable beyond an approximate guide for estimate. Although the water-works pumping engine has been brought largely to a commercial basis in manufacture and sale, the conditions under which it must operate are special for the location where wanted, and all prices pertaining to specially defined contracts are more or less changeable.

The following table gives an example of how methodically the cost of plants built on the unit basis may be determined. In some cases these figures may be too high and in others too low; they are closely approximate, and enough of the data are based on records fairly to insure the figures in the table as safe for practical use in making estimates. However, the table is so close that it would be taking chances for an engineer or a contractor to guarantee the production of results for the figures named, without inevstigating each case by itself. The work contemplated is for the best type of modern, triple-expansion pumping engines, and high-pressure boilers. The buildings are assumed to be of good design and quality; of brick, or of stone where stone is cheap; the roofs steel-trussed and slate-covered; the chimneys adequate; and the intakes properly proportioned and thoroughly screened. The cost given includes everything except the land.

COST OF COMPLETE PUMPING STATIONS.

Pressure of water load pumped against, in lbs. per sq. in.	Cost of plant, per mill. gal. capac., incl. reserve	Pressure of water load pumped against, in lbs. per sq. in.	Cost of plant, per mill. gal. capac., incl. reserve
30	$6,750	90	$8.250
40	7.000	100	8.500
50	7.250	110	8.750
60	7.500	120	9,000
70	7.750	130	9,250
80	8,000	...	....

There are cheaper classes of pumping engines, but they are necessarily of lower economic efficiency, and therefore require more boiler capacity, more coal storage, and other incidentals which, when balanced up, will tend to keep the figures about the same. A cheaper and less durable building may be used, but in the long run this will need more repairs, which when capitalized will bring the account fully up to the figures given and most likely exceed them.

It is scarcely possible that the cost of equipping pumping stations for water-works will be increased much on account of a higher type of steam machinery, because it is evident that the top limit has just about been reached, with the record of a little more than 181,000,000 ft. lbs. per 1,000 lbs. of steam. Ten years ago it nearly touched the 180,000,000 mark; and a gain of 0.8 of 1% in ten years, with every nerve strained, is eloquent evidence of the top limit. The Mariotte curve is about the nearest approach to perfection possible for the steam engine to accomplish, in expressing the relation between the work done and the amount of steam used. If the terminal pressure is taken as expressing the steam used, and all the steam is accounted for by the diagram, then 96% mechanical efficiency of the machine, will be the resulting figures, with a reasonable amount of steam used in the jackets and reheaters charged against the account.

If there were no necessity for the use of steam jackets, or jacket steam, the figures would approach 200,000,000 rather closely, and if superheating can save jacket steam, and vitalize the working steam in the cylinders, the latter figure may be reached in the near future, as far as the official test is concerned. This pleasing result may have to be obtained, however, by the use of a surface condenser with a comparatively small air-pump, and this type of condenser may require more maintenance account than the jet form; and the superheat may have to be obtained at the cost of coal.

Pumping Engine Economy. A critical discussion of the results obtained by the Nordberg and other high-duty engines is printed in Engineering News, Sept. 27, 1900. It is shown that the practical question in most cases is not how great fuel economy can be reached, but how economical an engine it will pay to install, taking into consideration interest, depreciation, repairs, cost of labor and of fuel, etc. The following table is given showing that with low cost of fuel and labor it does not pay to put in a very high duty engine. Accuracy is not claimed for the figures; they are given only to show the method of computation that should be used, and to show the influence of different factors on the final result.

Cost of Electric Current for Pumping 1,000 Gallons per Minute 100 ft. High. (Theoretical h. p. with 100% efficiency = 100,000 ÷ 3958.9 = 25.259 h.p.)

Assume cost of current = 1 ct. per kw. hour delivered to the motor: efficiency of motor = 90%; mechanical efficiency of triplex pumps = 80%; of centrifugal pumps = 72%; combined efficiency,

TABLE XXIX. ANNUAL COST OF PUMPING WITH AN 800-H.P. ENGINE, AS INFLUENCED BY VARYING DUTY OF ENGINE, VARYING PRICE OF FUEL, AND VARYING TIME OF OPERATION.

	Duty per million B. t. u.				
First cost:	50	100	120	150	180
Engine	$24,000	$48,000	$68,000	$118,000	$148,000
Engine, per h.p....	30.00	60.00	85.00	147.00	185.00
Boilers, economizers	27,000	13,500	11,250	9,000	7,500
Engine and boilers	51,000	61,500	79,250	127,000	155,500
Interest and depreciation:					
On engine, at 6%..	1,440	2,880	4,080	7,080	8,880
Boilers, 8%	2,160	1,080	900	720	600
Total depreciation	3,600	3,960	4,980	7,800	9,480
Labor per annum....	6,022	6,022	7,655	9,307	10,220
Fuel cost:					
4,000 hrs. per yr.:					
$3 per ton	17,280	8,640	7,200	5,760	4,800
$4 per ton	23,040	11,520	9,600	7,680	6,400
$5 per ton	28,800	14,400	12,400	9,600	8,000
6,000 hrs. per yr.:					
$3 per ton	25,920	12,960	10,800	8,640	7,200
$4 per ton	34,560	17,280	14,400	11,520	9,600
$5 per ton	43,200	21,600	18,600	14,400	12,000
Total annual cost:					
4,000 hrs. per yr.:					
Coal, $3 per ton...	26,902	18,622	19,835	22,867	24,500
4 per ton...	32,662	12,502	22,235	24,787	25,100
5 per ton...	38,422	24,382	25,035	26,707	27,700
6,000 hrs. per yd.:					
Coal, $3 per ton...	35,522	22,942	23,435	25,747	26,900
4 per ton...	44,182	27,262	27,035	28,627	29,300
5 per ton...	52,822	31,582	31,235	31,507	31,700

triplex pumps, 72%; centrifugal, 64.8%. 1 kw. = 1.34 electrical h.p. on wire.

Triplex, $1.34 \times 0.72 = 0.9648$ pump h.p.; $\times 33,000 = 31,838$ ft. lbs. per min.

Centrifugal, $1.34 \times 0.648 = 0.86382$ pump h.p.; $\times 33,000 = 28,654$ ft.-lbs. per min.

1,000 gals. 100 ft. high = 833,400 ft.-lbs. per min.

Triplex, $833,400 \div 31,838 = 26.1763$ k.w. $\times 8,760$ hrs. per year $\times$ $0.01 = $2,293.04.

Centrifugal, $833,400 \div 28,655 = 29.0840$ k.w. $\times 8,760$ hrs. per year $\times$ $0.01 = $2,547.76.

For 100% efficiency, $2,293.04 × 0.72 = $1,650. For any other efficiency, divide $1,650 by the efficiency. For any other cost per kw.-hr. in cts., multiply by that cost.

Cost of Pumping 1,000 Gal. per Min. 100 ft. High by Gas Engines. Assume a gas engine supplied by an anthracite gas producer using 1.5 lbs. of coal per brake h.p.-hr., coal costing $3 per ton of 2,000 lbs.

Efficiency of triplex pump 80%, of centrifugal pump, 72%.

TABLE XXX. COST OF FUEL PER YEAR FOR PUMPING 1,000 GAL. PER MIN. 100 FT. HIGH BY STEAM PUMPS

(1)	(2) Efficiency 100%	90%	(3)	(4)	(5)	(6)	(7)
10.	198.	178.2	142.56	0.5846	0.42090	153.63	460.89
11.88	166.667	150.	120.	0.6945	0.50004	182.51	547.53
14.	141.433	127.87	101.83	0.8184	0.58926	215.08	645.24
14.256	138.889	125.	100.	0.8334	0.60005	219.02	657.06
15.	132.	118.8	95.04	0.8769	0.63125	230.44	691.32
16.	123.75	111.375	89.10	0.9354	0.67344	245.80	737.40
17.82	111.111	100.	80.	1.0417	0.75006	273.77	821.31
20.	99.	89.1	71.28	1.1692	0.84180	307.26	921.78
23.76	83.333	75.	60.	1.3890	1.00008	365.03	1095.09
30.	66.	59.4	47.52	1.7538	1.26270	460.89	1382.67
35.64	55.556	50.	40.	2.0835	1.50012	547.54	1642.62
40.	49.5	44.5	35.64	2.3384	1.68360	614.52	1843.56
47.52	41.667	37.5	30.	2.7780	2.00016	730.06	2190.18
50.	39.6	35.64	28.51	2.9230	2.10450	768.15	2304.45
a	b	c	d	e	f	g	h

(1) Lbs. steam per i.h.p. per hour.
(2) Duty million ft.-lbs. per 1,000 lbs. steam, b, 100% effy., c. 90%.
(3) Duty per 100 lbs. coal, 90% effy., 8 lbs. steam per lb. coal.
(4) Lbs. coal per min. for 1,000 gals., 100 ft. high.
(5) Tons, 2,000 lbs., in 24 hrs.
(6) Tons per year, 365 days.
(7) Cost of fuel per year at $3.00 per ton.

Factors for calculation: $b = 1980 \div a$; $c = b \times 0.9$; $d = c \times 0.8$; $e = 8334 \div 1000\ d$; $f = e \times 0.72$; $g = f \times 365$; $h = g \times 3$.

For any other cost of coal per ton, multiply the figures in the last column by the ratio of that cost to $3.00.

1,000 gals. per min. 100 ft. high = 833,400 ft.-lbs. per min. ÷ 33,000 = 25.2545 h.p.

Fuel cost per brake h.p.-hr. 1.5 lbs. × 300 cts. ÷ 2,000 = 0.225 ct. × 8,760 hrs. per year = $19.71 per h.p. × 25.2545 = $497.766 for 100% efficiency.

For 80% efficiency, $622.21; for 72% efficiency, $691.34; or the same as the cost with a steam pumping engine of 95,000,000 ft.-lbs. duty per 100 lbs. of coal.

Cost of Fuel for Electric Current. Based on 10 lbs. steam per 1 h.p.-hour, 8 lbs. steam per lb. coal, or 1.25 lbs. coal per 1. h.p. per hour. (Electric line loss not included.)

Efficiency of engine 0.90, of generator 0.90, combined efficiency 0.81.

1 h.p. = 0.746 kw., 0.746 × 0.81 = 0.6426 kw. on wire for 10 lbs. steam. Reciprocal = 16.5492 lbs. steam per kw. hour. 8 lbs. steam per lb. coal = 2.06865 lbs. coal, at $3.00 per ton of 2,000 lbs. = 0.3103 cent per kw-hour.

Lbs. steam per 1. h.p.-hr—						
12	14	16	18	20	30	40
Fuel cost, cents per k.w.-hr.—						
0.3724	0.4344	0.4965	0.5585	0.6206	0.9309	1.2412

Cost of Pumping Machinery for Water Works. W. H. Weston (Engineering Magazine, Jan., 1912) has published the following notes on the average cost of water works machinery:

AVERAGE COST OF PUMPING MACHINERY. Vertical triple-expansion crank and fly-wheel pumping engines per 1,000 gal. per 24 hrs.

Head pumped against, ft.

250 to 300	$6
150 to 200	5
50 to 75	4

Horizontal-compound fly-wheel pumping engines per 1,000 gals. per 24 hrs.

Head pumped against ft.

250 to 300	$5.00
150 to 200	4.00
50 to 75	3.50

Duplex compound direct-acting pumps per 1,000 gals. per 24 hrs. Head pumped against, ft.

250 to 300	$3.50
150 to 200	3.00
50 to 75	2.50

AVERAGE COST OF WATER-TUBE BOILERS FOR PUMPING ENGINES. Allowance made for reserve boilers.

Horsepower	Allowance for reserve per cent. of capacity of plant
400	33
600	33
800	25
1,000	20
1,500	15

Horsepower	Vertical triple-expansion crank and fly-wheel pumping engines	Compound condensing crank and fly wheel pumping engines
400	$4,000	$4,800
600	6,800	6,800
800	7,500	8,500
1,000	9,000	10,500
1,500	12,500	14,500

COST OF STEAM AND WATER PIPING, VALVES AND SEPARATORS.

(Pump piping not included).

Horsepower	Vertical triple-expansion crank and fly-wheel pumping engines	Compound condensing crank and fly wheel pumping engines
400	$2,000	$2,300
600	2,600	3,100
800	3,200	3,800
1,000	4,000	4,800
1,500	6,200	7,300
Feed Pumps		
400	$90	$105
600	110	130
800	135	160
1,000	160	190
1,500	220	265
Heaters		
400	450	525
600	525	620
800	600	720
1,000	700	850
1,500	950	1,150

Vertical triple-expansion crank and fly-wheel pumping engines will use from 10½ to 11½ lbs. of steam per indicated h.p. per hr., for capacities between 10 and 35 million gallons per day, pumping against heads from 50 to 300 ft.

Compound engines of this type will take from 12½ to 13½ lbs. of steam per indicated h.p.-hr. To get the total h.p. that the engine must develop, Mr. Weston takes the h.p. represented by the amount of water to be pumped to the given height plus 10% for pump engine friction, and 4% for pipe-line friction and slippage of the pump. We have found in many cases that this is a very small percentage for slippage.

Cost of a Pumping Plant per Million Gallons Capacity. W. L. Du Moulin, in a paper presented before the American Society of Civil Engineers, June 2, 1915, describes the pumping plant of the Morenci Water Company, and gives the following costs:

The cost of pumping engines complete, with foundations, auxiliaries, condenser, piping, etc., per million gallons capacity per 24 hrs. was:

Triple-expansion pumping engines	$38,500
Cross-compound " "	29,400
Average of all " "	35,500

The cost of the boiler plant, including piping, foundations, etc., was:

Without economizers — per rated boiler h.p.	$30.50
With economizers " " " "	42.50

The total rated capacity of the boiler plant is 640 b.hp.

The cost of the pumping plant, including engines, boilers, economizers, piping, etc., per million gallons capacity per 24 hrs. was $41,500. These figures do not include anything for land, buildings, chimneys, wells, settling system, 10-in. pipe lines, etc., but practically only the items mentioned.

Comparison of the Costs of Pumping by Suction-Gas-Producer and Steam Engines was made in a paper by I. E. Gibson and S. H. Wright from an abstract of which in Engineering Digest we have taken the following:

The Gas Plant belongs to the Delaware Water Co. and is situated at the head of tide water on Christiana Creek.

FIXED CHARGES

	Gas plant	Steam plant
Management	$ 200	$ 200
Superintendence	920	920
Depreciation	1,694	1,987
Sinking fund	1,043	1,297
Interest	4,095	6,491
Insurance	76	250
Taxes	263	327
Total	$8,291	$11,472

TABLE XXXI. COST OF PUMPING ONE MILLION GALLONS 100 FT. HIGH WITH GAS AND STEAM.

	1908		1909		1910		1911		1912	
	Gas	Steam	Gas	Steam	Gas	Steam	Gas	Steam	Gas	Steam
Fixed Charges:										
Management	$ 0.995	$ 0.491	$ 0.589	$ 0.482	$ 0.318	$ 0.415	$ 0.301	$ 0.407	$ 0.293	$ 0.376
Superintendence	4.590	2.265	2.715	2.215	1.465	1.908	1.381	1.875	1.345	1.741
Depreciation	8.440	4.985	5.000	4.790	2.695	4.120	2.552	4.050	2.480	3.755
Sinking Fund	5.200	3.180	3.080	3.120	1.658	2.685	1.569	2.645	1.522	2.498
Interest	20.400	15.970	12.080	15.620	6.500	13.440	6.150	13.230	5.980	12.270
Insurance	0.379	0.615	0.224	0.602	0.121	0.519	0.114	0.509	0.111	0.473
Taxes	1.313	0.803	0.787	0.788	0.418	0.693	0.396	0.666	0.400	0.618
Total cost per annum	$41.317	$28.219	$24.475	$27.617	$13.175	$23.780	$12.463	$23.382	$12.131	$21.731
Operating Charges:										
Fuel	$ 2.615	$ 2.410	$1.441	$2.698	$1.291	$2.425	$1.505	$2.510	$1.860	$2.305
Oil, waste and packing	0.775	0.126	0.439	0.115	0.366	0.076	0.232	0.126	0.208	0.106
Pumping-station wages	7.490	6.210	5.470	5.825	3.615	4.790	3.787	4.450	3.670	4.520
Machinery repairs and building	0.432	0.072	0.631	0.0095	0.461	0.146	0.256	0.327	0.431	0.315
Miscellaneous expenses	0.322	0.133	0.300	0.0735	0.157	0.048	0.188	0.088	0.285	0.103
Total cost per annum	$11.634	$8.951	$8,281	$8,721	$5.890	$7.485	$5.968	$7.501	$6.454	$7.349
Total of operating and fixed charges	$52.951	$37.170	$32.756	$36.338	$19.065	$31.265	$18.431	$30.883	$18.585	$29.080

Average cost of pumping 1 million gal. 100 ft. high—gas.....$28.36
Average cost of pumping 1 million gal. 100 ft. high—steam... 32.95

The plant consists of two complete producer units rated at 110 h.p. each and two 13x12 in., single-acting, three-cylinder vertical gas engines of 89 b.h.p., each direct connected to a 13x15 in., single-acting triplex pump. The engines run at 265 r.p.m., and the pumps, through a 5 to 1 reduction gear, at 44 r.p.m., at which speed each has a capacity of 1,640,000 gals. per 24 hrs.

The cost of the plant was as follows:

Building and property	$38,750
Producers and engines complete, including auxiliaries	13,000
Pumps complete	7,250
Piping, air chambers, etc.	4,500
Total	$63,500
Cost of plant per brake horse-power	$392
Cost of plant per million gallons capacity per 24 hr.	19,250

A high grade of anthracite pea coal is used, costing $5.10 per long ton delivered into the storage bins.

The Steam Pumping Plant belongs to the Octoraro Water Co., and is located on the Octoraro Creek, near Quarryville, Penn. It consists of three 100 h.p. return-tubular boilers supplying steam to two horizontal, cross-compound condensing Corliss pumping engines, having 18 and 32 by 30 in. steam ends and 10x30 in. water ends delivering at a pressure of 150 lbs. These engines ran at 55 to 60 r.p.m. and are rated at three million gallons capacity. The cost of this plant was as follows:

COST OF STEAM PLANT

Building and land	$37,875
Boilers, engines, piping and auxiliaries	39,850
Total	$77,725
Cost of plant per brake h.p. allowing 10% for engine friction	$190
Cost of plant per million gallons capacity per 24 hrs.	12,100

The fuel used is high-grade bituminous, costing $4.40 per long ton delivered at the plant.

Comparative Cost of Plant and Operating Expenses for Pumps Driven by Reciprocating Steam Engines, Steam Turbines, and Diesel Oil Engines. The following figures from a paper by Francis Head before the Engineers' Club of Philadelphia, compare bids obtained by the City of Philadelphia in 1906 on low-lift pumping machinery for the Torresdale filters:

Coal Required for the Different Types and the Cost were as shown in Table XXXI.

The specifications called for six units of 40,000,000 gals. each. These were to lift the water from a conduit leading from the river and deliver it to pipes 5 ft. in diam., by which it was to be led to the preliminary filters. The maximum lift measured from the surface of the water to the discharge side of the pump was 45 ft., no allowance being made for the velocity head in the water of discharge. Each bidder was required to furnish a complete plant as far as the machinery went, including engines, ping, boil-

ers, etc., and to operate it for six months, and to make tests of 24 hrs. and 30 days, respectively, to determine the duty and capacity.

TABLE XXXII. COMPARATIVE BID PRICES ON STEAM ENGINES, TURBINES AND DIESEL ENGINES

	Steam engines	Turbines	Diesel oil engines
Time required in days to furnish plant	245	300	250 for half plant. 315 for whole plant.
Duty in million foot-lbs. per 100 lbs. steam.....	85 and 70 millions.	88 and 83 millions.	95 and 90 millions per 5 gals. oil.
Price bid	$205,400	$178,000	$298,000
Extra for house	52,528	60,207	....
Electric plant and stack..	20,000	20,000	....
Cost of plant	$277,928	$258,207	$298,000
Extra for time at $250 per day	....	$13,750	$17,500
Extra cost of coal over oil per year	$12,180	3,068	....
Extra cost of coal over oil per year. Capitalized at 3.5%	345,100	87,650	....
Comparative price based on duty	$623,028	$359,607	$315,500
Boiler room, labor and repairs	$10,150	$10,150	....
Extra cost of operating steam plants per year..	22,230	13,218	....
Extra cost of operating steam plants per year. Capitalized at 3.5%....	635,100	377,650	....
Comparative price based on duty and labor saved...	$913,028	$649,607	$315,500

TABLE XXXIII. COST OF COAL FOR VARYING PUMPING ENGINE DUTY.

	Lbs. coal per hp. hour	315.6 hp. lbs. per coal per hour	24 hours	Cost per pump per 24 hours
70 million duty	2.83	893	21,435	$31.57
83 " "	2.39	753	18,072	26.63
90 " "	...	...	.....	24.95

The specifications stated that bids were to be made on the following basis: The value of money will be taken at 3½% per annum. After the bids are scheduled drawings will be prepared giving the necessary dimensions for the engine and boiler rooms to house the different classes of machinery. The cost of the buildings will be computed at 15 cts. per cu. ft., measuring from the engine and boiler room floors to midway between the top of the walls and the ridge purlin; and the amount thus obtained will be used in ascertaining the cost of installation. In comparing the cost of operation coal will be figured at $3.30 per ton of 2,240 lbs.

and fuel oil will be figured at 3 cts. per gal. In comparing the bids with reference to the time for starting the machinery in operation, allowance will be made at the rate of $250 per calendar day for the bids specifying earlier dates of completion as compared with the bid specifying the longest time. In addition to this, there was a clause providing in case of failure to meet duty guaranteed, that for each million foot-pounds duty the pumping engines fall below the duty specified in the bid there will be deducted $1,000 from the contract price for each engine.

The duty guaranteed for the 24-hr. run by the steam engines was 85,000,000 ft.-lbs. per 100 lbs. of steam; by the turbines 88,000,000, and by the oil engines 95,000,000. For the 30-day test the duty guaranteed by the steam engines was 70,000,000; by the turbines 83,000,000, and by the oil engines 90,000,000.

Forty million gallons per day against 45-ft. head requires 315.6 h.p. in the water column. The I. P. Morris Co., whose design for the pumps was used by the Diesel Co., guaranteed 70% efficiency under the conditions of the contract, the pump shaft required 450 h.p.

With the Diesel engine 5 gals. of oil, fuel oil of commerce being used, per 90,000,000 ft.-lbs. means 34.65 gals. per pump per hr., costing $1.0395, or $24.95 per 24 hrs. per unit.

The fuel saving per pump by the oil engine over the steam units, is as follows:

	Per hour	Per year
Steam engines	$6.62	$12,080
Turbines	1.68	3,080

It should be further noted that each of the steam propositions emphasized the fact that the coal furnished must have 14,500 B.t.u., or if it were less, due allowance must be made, which means that these guarantees were made on a good grade of bituminous coal.

For the purpose of comparison, the duty on the 30-day test alone was used.

In comparing the actual cost of the plants to the city, according to the table, the turbine is the lowest, being $258,000; the steam engine comes next, $278,000, the oil engine being the highest at $298,000. In making this comparison the foundations of the boilers and ash tunnels have not been included. When the extra cost of operating the steam plants over the oil engine is capitalized at 3½% in accordance with the specifications, and due allowance has been made for penalizing the oil engine and steam turbine, it will be seen that the cost of the oil engine was approximately $315,500, the turbine engines was $649,600, and the steam engines was $913,000. The bid for steam engines was accepted.

Cost of Pumping Oil Long Distances. According to a memorandum in the Engineering and Mining Journal in 1907, the cost of pumping oil as reported by the Interstate Commerce Commission amounted to about 2 cts. per barrel for a distance of about

100 miles. Therefore the cost to the Standard Oil Company of transporting a barrel from the Kansas oil field to the Atlantic seaboard would not be much, if any, in excess of 30 cts.

Cost of Pumping for Municipalities. The data in Table XXXIV from Engineering News, Aug. 12, 1909, give the cost of pumping in Philadelphia taken from annual reports of the Bureau of Water:

TABLE XXXIV. COST OF PUMPING IN PHILADELPHIA BY YEARS

Year	Billions of gals. 100 ft.	Fuel cost per mil. gals. 100 ft.	Pay of employees per mil. gals. 100 ft.	Total cost per mil. gals. 100 ft.
1894	121.2	$1.87	$0.98	$3.48
1895	132.0	2.08	1.00	3.69
1896	161.8	2.00	0.92	3.43
1897	187.4	1.86	0.84	3.16
1898	210.8	1.77	0.84	2.97
1899	231.8	1.77	0.80	2.90
1900	218.1	2.11	1.06	3.71
1901	227.7	2.04	1.31	4.14
1902	239.7	2.55	1.63	4.80
1903	248.8	2.99	1.54	5.20
1904	251.2	2.93	1.49	5.11
1905	261.3	2.55	1.47	4.61
1906	257.3	2.52	1.57	5.06
1907	242.3	2.57	1.82	5.68

Operating Costs of Various Pumping Stations. Dabney H. Murray (Engineering and Contracting, Mar. 6, 1912) gives the operating costs of various reciprocating engine pumping plants in Chicago as follows:

Private Plant No. 1. The boiler equipment at this plant is as follows: Four 350 h.p. Babcock and Wilcox boilers, extension front, Hawley down draught, gravity fed, and two 350 h.p. B. & W. boilers, flush front, Hawley, hand fired. The total rated boiler h.p. is 2,100, the average h.p. on day watch is 1,400, and the load factor is 67%.

The engine equipment is as follows: Two 65 h.p., two 250 h.p., and one 140 h.p. simple horizontal engines. Two 110 h.p. simple vertical engines, one 220 h.p. simple 2-cylinder vertical engines, one 33 h.p. 25 k.w. electric light engine, and one 30 h.p. 10 in. and 6 in. and 10 in. x 16 in. elevator pump. The total rated engine h.p. is 1,283, the average h.p. on day watch 400, and the load factor 28%.

The daily payroll for this plant, for 12-hr. shift, is as follows:

2 firemen at $3.10	$ 6.20
4 firemen helpers at $2.68	10.72
1/6 ashman at $2.50	.42
Total for boiler room	$17.34
2 chief engineers at $3.48	6.96
2 asst. engineers at $2.68	5.36
2 oilers at $2.41	4.82
1/30 window washer at $2.25	.08

1/30 machinist at $3	.10
1/30 steamfitter at $3	.10
	$17.42
½ janitor (added) at $2.40	1.20
½ machinist (added) at $3	1.50
	$20.12
1 asst. engr. (deducted)	2.68
Total	$17.44

The maximum number of boilers per fireman per watch is 1⅓, and the maximum h.p. per fireman per watch is 467. By hand firing 2,000 lbs. of Pocahontas coal is fired per hour per fireman on the average on the day watch, and 1,800 lbs. of Illinois slack coal.

The number of city pumping engines equivalent to average number of units in service is 2, the average equivalent number of pumping engines per engineer per watch, as corrected is 1½, and per oiler per watch is 2. The ratio of cost of coal to cost of labor, as corrected, $1.48. The actual daily payroll is $57.72, and as corrected $23.64. The average pay per man per day is $2.62 and per hr. is $0.33. The actual engine h.p. per dollar of daily payroll, as corrected, is 16.9.

As engine room and machinery are not well kept, half time for one janitor and half time for one machinist are added. But as the average engine horse power is only 28% of average boiler h.p., the balance being used for other purposes, and as the engineers and others have other duties besides the care of the machinery, the total pay roll, for the purpose of figuring the corrected items, is taken at $17.44 plus $6.20 = $23.64.

Private Plant No. 2. The boiler equipment at this plant is as follows: Five 375 h.p. Stirling water tube boilers with Greene chain grates, hand fired. The rated boiler horse power is 1,875, the average h. p. on the day watch is 960, and the load factor is 51%.

The engine equipment is as follows: Five 250 h.p. vertical compound, non-condensing engine generators, one 400 h.p. 3-cylinder, horizontal compound, non-condensing elevator pump, two 200 h.p. 3-cylinder, horizontal compound, non-condensing elevator pump, two 30 h.p. 10 in. and 18 in. x 24 in. horizontal vacuum pumps, one 30 h.p. horizontal compound, duplex house pump, one 25 h.p. horizontal simple, duplex house pump, and three 5 h.p. motor-driven elevator return pumps. The rated h.p. of the total engine and motor units is 2,180, the average h.p. on day watch 1,210 and the load factor 55%.

The daily payroll for this plant, for an 8-hr. shift, is as follows:

3 firemen at $2.40	$ 7.20
6 coal passers at $2.32	13.92
Total for boiler room	$21.12
1 chief engineer at $5	5.00
3 asst. engineers at $3.60	10.80
4 oilers at $2	8.00

2 repairmen at $2.20	$ 4.40
1 machinist at $3.60	3.60
1 janitor at $2	2.00
1 steamfitter at $2.80	2.80
	$36.60
2 oilers (added) at $2.00	4.00
Total	$40.60

The maximum number of boilers per fireman per watch is 1, and the maximum h.p. of boilers per fireman per watch is 465. On an average 2,000 lbs. of coal is fired by hand per hour per fireman on the day watch.

The number of city pumping engines equivalent to average number of units in service is 3, the average equivalent number of pumping engines per engineer per watch is 2¼, the average equivalent number of pumping engines per oiler per watch is 1½, as corrected. The ratio of cost of coal to cost of labor is 2.96, as corrected. The actual daily payroll is $57.72, and, as corrected, is $61.72. The average pay per man per day is $2.62, and per hr. is 22 cts. The actual engine h.p. per dollar of daily payroll is 19.6 as corrected.

Part of this plant does not run at night. In order to figure the corrected items above, two oilers were added, who would be the only extra men needed for full 24-hr. service.

Private Plant No. 3. The boiler engine, and motor equipment of this plant is as follows: Four 400 h.p. Heine water-tube boilers with Murphy stokers, gravity fed. The rated boiler h.p. is 1,600, the average horse power on day watch is 880, and the load factor 55 per cent.

There are two 470 h.p. simple horizontal, non-condensing engine generators, one 335 h.p. simple horizontal, non-condensing engine generators, and two 10 h.p. motor-driven air compressors. The rated h.p. of the total engine and motor units is 1,295, the average h.p. on day watch 1,050, and the load factor 81%.

The daily payroll for this plant, for an 8-hr. shift, is as follows:

3 firemen at $2.17	$ 6.50
3 coal passers at $1.67	5.00
3 ash wheelers at $1.67	5.00
½ boiler washer at $2.50	1.25
1 helper at $1.83	1.83
Total for boiler room	$19.58
½ chief engineer at $4.67	2.33
1½ asst. engineer at $2.92	4.38
3 oilers at $1.93	5.80
1 janitor at $1.67	1.67
1 laborer at $1.67	1.67
1 machinist at $3	3.00
	$18.85
½ chief engineer (added) at $4.67	2.33
½ asst. engineer (added) at $2.92	1.46
1 laborer (added) at $1.67	1.67
Total	$24.31

The maximum number of boilers per fireman per watch is 1½, and the maximum h.p. per fireman per watch is 440. There are 5,000 lbs. of coal, gravity fed, per hour per fireman on the average during the day watch.

The number of city pumping engines equivalent to the average number of units in service is 1.4; the average equivalent number of pumping engines per engineer per watch is 2.1, as corrected; the average equivalent number of pumping engines per oiler per watch is 1.4 as corrected. The ratio of cost of coal to cost of labor is 3.33, as corrected. The actual daily payroll is $38.43, and as corrected is $43.89. The average pay per man per day is $2.08, and per hr. is 26 cts. The actual engine horse power per dollar of daily payroll is 17.1 as corrected.

Private Plants Nos. 3 and 4 are near each other and are operated by the same management, some of the men dividing their time between the two plants. Neither runs full 24 hrs. For the purpose of figuring the corrected items given under plants 3 and 4, enough men were added to the payroll of each plant to run the plants independently of each other, and also to provide for full 24-hr. service.

Private Plant No. 4. There are four 450 h.p. Stirling water tube boilers, with chain grates, gravity fed. Their rated h.p. is 1,800, the average h.p. on day watch is 990, and the load factor is 55%. There is one 140 h.p. horizontal compound pump, handling 2,000,000 gals. against 150 lbs., used occasionally for elevator service.

The engine and pump equivalent is as follows: Two 140 h.p. vertical compound pumps, each handling 2,000,000 gals. against 150 lbs.; one 670 h.p. 500 k.w. vertical compound engine generator, two 430 h.p. 320 k.w. vertical compound engine generators; two 268 h.p., 200 k.w., vertical compound engine generators; two 134 h.p., 100 k.w. vertical compound engine generators; one 40 h.p. house pump; one 50 h. p. house pump, and three 10 h.p. elevator return pumps.

The total rated h.p. of the engine and pump units is 2,874, the average h.p. on day watch is 1,186, and load factor is 41%.

The daily payroll, for 8-hr. shift, is as follows:

3 firemen at $2.17	$ 6.50
3 coal passers at $1.67	5.00
3 ash wheelers at $1.67	5.00
½ boiler washer at $2.50	1.25
1 helper at $1.83	1.83
Total for boiler room	$19.58
½ chief engineer at $4.67	2.33
1½ asst. engineer at $2.92	4.38
3 oilers at $1.93	5.80
1 janitor at $1.67	1.67
1 laborer at $1.67	1.67
1 machinist at $3	3.00
	$18.85
½ chief engineer (added) at $4.67	2.33
½ asst. engineer (added) at $2.92	1.46
1 laborer (added) at $1.67	1.67
Total	$24.31

The maximum number of boilers per fireman per watch is 1½, and the maximum h.p. per fireman per watch is 495. During the day watch 5,610 lbs. of coal are gravity fed per hour per fireman.

The number of city pumping engines equivalent to the average number of units in service is 2.5; the average equivalent number of pumping engines per engineer per watch, as corrected, is 3.8; the average equivalent number of pumping engines per oiler per watch, as corrected, is 2.5. The ratio of cost of coal to cost of labor, as corrected, is 3.84. The actual daily payroll is $38.43, and, as corrected, is $43.89. The average pay per man per day is $2.08 and per hr. is 26 cts. The actual engine h.p. per dollar of daily payroll, as corrected, is 26.9.

Private Plant No. 5. The boiler equipment is as follows: Eight 500 h.p. Aultman-Taylor water tube boilers, with chain grates, gravity fed. The total rated boiler horse power is 4,000, the average h.p. on the day watch is 3,000, and the load factor is 75%.

The generating units are as follows: Three 1,200 h.p. horizontal compound condensing engines; one 800 h.p. horizontal compound condensing engine; one 100 h.p. horizontal simple engine; one 50 h.p. horizontal simple engine; one 60 h.p. 2-stage compound air compressor; one 80 h.p. 2-stage compound air compressor; two 90 h.p. horizontal compound duplex steam pumps; one 300 h.p. horizontal triple Corliss steam pump; one 300 h.p. compound elevator pump; one 75 h.p. horizontal compound elevator pump; three 90 h.p. horizontal duplex fire pumps; one 40 h.p. 30-ton ice machine; two 30 h.p. 10 in. and 18 in. x 20 in. vacuum pumps; and one 50 h.p. motor-driven duplex pump (not counted). The rated h.p. of the total generating units is 5,915, the average h.p. on the day watch is 2,900, and the load factor is 48%.

The daily payroll follows, firemen and assistant engineers working 8 hrs, all others 10 hrs.:

3 firemen at $2.14	$ 6.42
1 coal unloader at $2.20	2.20
3 asst. unloaders at $2	6.00
1 boiler washer at $2.70	2.70
2 asst. boiler washers at $2	4.00
Total in boiler room	$21.32
1 chief engineer at $5	5.00
3 asst. engineers at $3	9.00
5 oilers at $2	10.00
2 janitors at $2	4.00
1 machinist at $3	3.00
1 machinist helper at $2	2.00
Total	$33.00

The maximum number of boilers per firemen per watch is 6, and the maximum h.p. of boilers per fireman per watch is 3,000. On the day watch 15,833 lbs. of coal are gravity fed per hr. per fireman.

The number of City pumping engines equivalent to the average number of units in service is 5, the average equivalent number of

pumping engines per engineer per watch is 3.7, the average equivalent number of pumping engines per oiler per watch is 3. The ratio of cost of coal to cost of labor is 3. The actual daily payroll is $37.32, the corrected $54.32. The average pay per man per day is $2.49, per hr. 27 cts. The actual engine h.p. per dollar of daily payroll is 53.4.

Plant No. 5 does not run 24 hrs. The repair force is not sufficient to keep all the machinery in order. Three oilers, two assistant coal unloaders and one assistant boiler washer, amounting to $12 per day, were added to give 24 hr. service; and one machinist and one helper, amounting to $5 per day, were added to keep up repairs to machinery.

Private Plant No. 6. The boiler equipment is as follows: Ten 500 h.p. Aultman-Taylor, water tube boilers with chain grates, gravity fed and equipped with fuel economizers. Total rated boiler horse power 5,000, average horse power on day watch, 4,000, and load factor of 80%.

The engine, motor, pump and compressor units are as follows: One 400 h.p. 300 k.w. horizontal, compound, condensing engine; one 670 h.p. 500 k.w. horizontal, compound, condensing engine; one 1,340 h.p. 1,000 k.w. vertical compound condensing engine; one 1,610 h.p. 1,200 k.w. vertical compound condensing engine; one 670 h.p. 500 k.w. turbine generator (not counter); one 165 h.p. compound condensing air compressor; two 30 h.p. horizontal vacuum pumps; one 40 h.p. horizontal elevator pump; one 40 h.p. horizontal circulating pump; one 20 h.p., 16-ton ice machine; five motor-driven compressors or pumps (not counted); four 50 condensing sets. Total rated h.p. of engine, motor pump and compressor units is 4,545, average h.p. on daily watch 5,400, and load factor 119%.

The daily payroll follows:

3 firemen at $2	$ 6.00
3 asst. firemen, 8 hrs., at $1.92	5.76
2 water tenders, 10 hrs. at $2.80	5.60
2 ash shovelers, 10 hrs., at $2.40	4.80
For boiler room	$22.16
1 chief engineer, 10 hrs., at $6	6.00
3 asst. engineers, 8 hrs., at $3.29	9.87
6 oilers, 8 hrs., at $2	12.00
2 janitors, 10 hrs., at $2	4.00
1 machinist, 9 hrs., at $3	3.00
1 helper, 9 hrs., at $2	2.00
Total	$36.87

The maximum number of boilers per fireman per watch is 5, the maximum h.p. of boiler per fireman per watch is 2,000. On the day watch 8,600 lbs. of coal are gravity fed per fireman, on the average.

The number of City pumping engines equivalent to the average number of units in service is 8; the average equivalent number of pumping engines per engineer per watch is 6; and the average equivalent number of pumping engines per oiler per watch is 4.

The actual daily payroll is $45.43, the corrected $59.03. The average pay per man per day $2.52, per hr. 23 cts. The actual engine h.p. per dollar of daily payroll is 91.5.

Plant No. 6 does not run 24 hrs. One extra assistant shoveler, two janitors and two oilers are added to give 24 hr. service.

Kirtland Street Station, Cleveland, Ohio, Municipal Plant. There are eight 272.5 h.p. B. & W. water tube boilers, with superheaters and chain grates, gravity fed. The total rated boiler horsepower is 2,180, the average h.p. on the day watch is 1,140, and the load factor is 52%.

There are two 875 h.p. 25,000,000 gal. vertical triplex pumps, and three 585 h.p. 15,000,000 gal. horizontal compound pumps. The total rated h.p. of the engine units is 3,505, the average h.p. on the day watch is 1,820 and the load factor is 52%. One of the 585 h.p. units is located in a separate building, on opposite side of the boiler room from engine room in which the other four units are located.

The work is done in 8-hr. shifts, the watchmen working 12 hrs. The daily payroll follows:

4 firemen at $2.32	$ 9.28
6 firemen at $2	12.00
1 boiler cleaner at $2.56	2.56
1 boiler cleaner at $2	2.00
3 feed pump tenders at $2	6.00
Total for boiler room	$31.84
1 chief engineer at $6.03	6.03
1 asst. engineer at $4.11	4.11
2 operating engineers at $3.24	6.48
6 operating engineers at $3	18.00
2 clerks at $2.63	5.26
3 oilers at $2.16	6.48
3 oilers at $1.84	5.52
1 repair man at $2	2.00
1 janitor at $2.24	2.24
5 janitors at $1.76	8.80
1 pipe fitter at $3.52	3.52
1 pipe fitter helper at $2.24	2.24
1 machinist at $3.52	3.52
1 second machinist at $3.04	3.04
1 blacksmith at $3.04	3.04
2 blacksmith helpers at $2	2.00
2 watchmen at $2.64	5.28
	$87.56

The maximum number of boilers per firemen per watch is 2, and the maximum h.p. corresponding is 500. On the day watch there are 1,400 lbs. of coal gravity fired per hour per fireman.

The total number of engine units is 5. The number of City pumping engines equivalent to the average number of units in service is 7; the average equivalent number of pumping engines per engineer per watch is 2.1; the average equivalent number of pumping engines per oiler per watch is 3.5. The ratio of the cost of coal to cost of labor is 0.90. The daily payroll is $119.42.

The average pay per man per day is $2.49, per hr. is 31 cts. The actual engine h.p. per dollar of daily payroll is 15.2.

North Point Station, Milwaukee, Wis., Municipal Plant. There are six 125 h.p. horizontal tubular boilers with Hawley down draught furnaces, flush front, hand fired, and three 150 h.p. horizontal tubular boilers, with Hawley down draft furnaces, extension front, hand fired. The total rated boiler h.p. is 1,200, the average boiler h.p. on the day watch is 470, and the load factor is 39.1%.

The engine units are as follows: two 218 h.p. 8,000,000 gal., vertical compound, condensing beam engines; one 327 h.p. 12,000,000 gal. Vertical Steeple compound, condensing engine, one 490 h.p., 18,000,000 gal. vertical triplex condensing engines; two 545 h.p. 20,000,000 gal. vertical triplex condensing engines, and one 561 h.p. 12,000,000 gal. vertical triplex condensing engine. The rated h.p. of the total of the engine units is 2,904, the average h.p. on the day watch is 994, and the load factor is 34.2%. There are two separate boiler rooms, one on each side of the engine room.

The work is done in 8-hour shifts. The daily payroll follows:

6 firemen at $2.33	$14.00
3 coal passers at $2	6.00
½ coal weigher at $1.83	.92
½ coal trimmer at $1.67	.83
	$21.75
1 engineer in charge at $4.17	4.17
3 asst. engineers at $3.50	10.50
6 oilers at $2.33	14.00
½ machinist at $2.78	1.39
½ blacksmith at $2.50	1.25
½ blacksmith helper at $2	1.00
½ carpenter at $2.33	1.67
2 janitors at $2	4.00
5 helpers, etc., at $2	10.00
	$47.98

The maximum number of boilers per fireman per watch is 3, and the maximum h.p. corresponding is 300. On the day watch there are 855 lbs. of coal hand fired per hour per fireman.

The total number of engine units is 7. The number of city pumping engines equivalent to the average number of units in service is 4; the average equivalent number of pumping engines per engineer per month is 3; the average equivalent number of pumping engines per oiler per watch is 2. The ratio of the cost of coal to cost of labor is 0.96. The daily payroll is $69.73. The average pay per man per day is $2.40, per hr. is 30 cts. The actual engine h.p. per dollar of daily payroll is 14.3.

Peoria, Illinois, Pumping Station. Private Plant. There are six 150 h.p. Heine water tube boilers, with plain grates, hand fired, and three 400 h.p., 7,000,000 gal., vertical compound condensing pumping engines. The total rated h.p. of the boilers is 900 and of the engines 1,200. The average h.p. on the day watch is 300 for the boilers and 400 for the engines, the load factor being 33% for both.

The firemen work 9 hrs. and the assistant firemen 8½ hrs.; all others work 10 hrs.

3 firemen at $2	$ 6.00
1 asst. fireman (who washes boilers, cleans filters, wheels ashes, etc.) at $1.83	1.83
1 coal passer at $1.75	1.75
	$9.58
1 chief engineer at $3.89	3.89
2 asst. engineers at $2.50	5.00
1 machinist at $2.50	2.50
1 oiler and wiper at $1.83	1.83
1 laborer at $1.75	1.75
	$14.97

The maximum number of boilers per fireman per watch is 2 and the maximum h.p. corresponding is 300. On the day watch there are 1,833 lbs. of coal hand fired per hour per fireman.

The number of city pumping engines equivalent to the average number of units in service is 1⅓; the average equivalent number of pumping engines per engineer per watch is 1⅓; the average equivalent number of pumping engines per oiler per watch is 4. The ratio of the cost of coal to cost of labor is 1.08. The daily pay roll is $24.55. The average pay per man per day is $2.23, per hour is 25 cts. The actual engine h.p. per dollar of daily pay roll is 16.3.

Chicago City Pumping Station. Statistics of the eight major pumping stations of Chicago are given below. In all cases the men at the stations work 8 hrs. a day.

Chicago Avenue Pumping Station. There are six 250 h.p. Scotch marine boilers, with Hawley down draught furnaces, gravity fed, erected 1900 to 1904. There are two 235 h.p., 12,000,000 gals., horizontal compound, Gaskill engines, piston speed 116 ft., 17.3 r.p.m., erected 1887; and three 4498 h.p., 25,000,000 gals., vertical triple, Allis engines, speed of piston 488 ft., 61 r.p.m., erected 1904 to 1906. The total rated boiler h.p. is 1,500, and the engine h.p. 1,964. The average boiler h.p. under service is 1,000 and the engine h.p. 1,380. The boiler load factor is 67%, and the engine load factor 70%.

The daily pay roll follows:

11 firemen at $2.96	$ 32.56
5 coal passers at $2.74	13.70
1 boiler washer at $3.42	3.42
1 conveyor engineer at $3.29	3.29
	$ 52.97
1 chief engineer at $6.85	6.85
6 asst. engineers at $5.48	32.88
12 oilers at $2.96	35.52
1 janitor at $2.47	2.47
1 well tender at $2.74	2.74
5 laborers at $2.50	12.50
6/7 steamfitter at $5.50	4.70
6/7 steamfitter helper at $3.50	3.00
12/7 machinist at $5	8.55
	$109.21

The maximum number of boilers per fireman per watch is 1.1 and the maximum h.p. corresponding is 273. On the day watch there are 1,130 lbs. of coal gravity fired per hr. per fireman.

The total number of engine units is 5. The number of city pumping engines equivalent to the average number of units in service is 3.6; the average equivalent number of pumping engines per engineer per watch is 1.5; the average equivalent number of pumping engines per oiler per watch is 0.9. The ratio of the cost of coal to cost of labor is 0.83. The daily pay roll is $162.18. The average pay per man per day is $3.40, per hr. is 42.5 cts. The actual engine h.p. per dollar of daily pay roll is 8.5.

Fourteenth Street Pumping Station. There are six 250 h.p. Scotch marine boilers, with Hawley down draught furnaces, gravity fed, erected in 1904, and three 200 h.p. B. & W. water tube boilers, with Roney stokers, erected in 1898, but not now in use.

There are three 296 h.p., 15,000,000 gal. vertical, triple, Allis engines, 159 ft. piston speed, 15.9 r.p.m., erected in 1891–92, and one 592 h.p., 30,000,000 gal., vertical, triple, Lake Erie engine, 123 ft. piston speed, 19.3 r.p.m., erected in 1898. The total rated h.p. of the boilers is 1,500 and of the engines is 1,480. The average h.p. developed by the boilers is 1,000 and by the engines is 1,406, the load factors being 67% for the boilers and 95% for the engines.

The daily pay roll is as follows:

4 coal passers at $2.96	$29.60
10 firemen at $2.74	10.96
1 boiler washer at $3.42	3.42
1 conveyor engineer at $3.29	3.29
	$47.27
1 chief engineer at $6.85	6.85
3 asst. engineers at $5.48	16.44
13 oilers at $2.96	38.48
1 janitor at $2.47	2.47
2 laborers at $2.50	5.00
6/7 steamfitter at $5.50	4.70
6/7 steamfitter helper at $3.50	3.00
6/7 machinist at $5	4.28
	$81.22

The maximum number of boilers per fireman per watch is 1.2, and the maximum h.p. corresponding is 300. On the day watch there are 1,370 lbs. of coal gravity fired per hour per fireman.

The total number of engine units is 4. The number of city pumping engines equivalent to the average number of units in service is 4.4; the average equivalent number of pumping engines per engineer per watch is 3.3; the average equivalent number of pumping engines per oiler per watch is 1.0. The ratio of the cost of coal to cost of labor is 1.15. The daily pay roll is $128.49. The average pay per man per day is $3.36, per hr. is 42 cts. The actual engine h.p. per dollar of daily pay roll is 10.9.

Sixty-eighth Street Pumping Station. There are four 100 h.p. and four 129 h.p. horizontal, tubular boilers with common grates,

hand fired, the former erected in 1898 and the latter in 1890; and four 340 h.p. B. & W. water tube boilers with chain grates, gravity fed, erected in 1906.

There are four 263 h.p., 12,000,000 gal. horizontal, compound, Gaskill engines, 108 ft. piston speed, 16.2 r.p.m., erected 1886 to 1898, and one 263 h.p. 12,000,000 gal. horizontal compound, Worthington engine, 96 ft. piston speed, 12 r.p.m., erected in 1890, and one 308 h.p., 14,000,000 gal., horizontal, compound, Holly engine, 120 ft. piston speed, 18 r.p.m., erected 1898, and one 438 h.p., 20,000,000 gal., horizontal, compound, Snow engine, 305 ft. piston speed, 43.5 r.p.m., erected 1906. The total rated h.p. of the boilers is 2,276 and of the engines is 2,061. The average h.p. developed by the boilers is 1,196 and by the engines is 1,700, the load factor being 53% and 82% respectively.

The daily pay roll is as follows:

10 firemen at $2.96	$ 29.60
8 coal passers at $2.74	21.92
1 boiler washer at $3.42	3.42
6/7 crane engineer at $5.60	4.80
	$ 59.74
1 chief engineer at $6.85	6.85
3 asst. engineers at $5.48	16.44
21 oilers at $2.96	62.16
1 janitor at $2.47	2.47
1 well tender at $2.74	2.74
5 laborers at $2.50	12.50
1 rigger at $2.63	2.63
6/7 steamfitter at $5.50	4.70
6/7 steamfitter helper at $3.50	3.00
12/7 machinists at $5	8.55
6/7 machinist helper at $3.20	2.74
	$124.78

The maximum number of boilers per fireman per watch is 1.8 and the maximum h.p. corresponding is 362. On the day watch there are 590 lbs. of coal hand fired and 6,650 lbs. gravity fed per hr. per fireman.

The total number of units is 7. The number of city pumping engines equivalent to the average number of units in service is 5.6; the average equivalent number of pumping engines per engineer per watch is 4.2; the average equivalent number of pumping engines per oiler per watch is 0.6. The ratio of the cost of coal to cost of labor is 0.82. The daily pay roll is $184.52. The average pay per man per day is $3.23, per hour is 40.4 cts. The actual engine h.p. per dollar of daily pay roll is 9.2.

Twenty-second Street Pumping Station. There are six 161 h.p., horizontal, tubular boilers with Hawley down draught furnaces, hand fired, erected 1884, and six 137 h.p., horizontal, tubular boilers with Hawley down draft furnaces, hand fired, erected 1894.

There are two 267 h.p., 15,000,000 gal., vertical, compound, Beam Quintard, Corliss engines, 196 ft. piston speed, 9.8 r.p.m., erected 1876, and two 267 h.p., 15,000,000 gal., vertical, compound, Beam

Quintard, Corliss engines, 187 ft. piston speed, 9.4 r.p.m., erected 1884. The total rated h.p. of the boilers is 1,788 and of the engines is 1,068. The average h.p. developed by the boilers is 1,100 and by the engines is 965, the load factor being 62% for the boilers and 90% for the engines.

The daily pay roll is as follows:

15 firemen at $2.96	$44.40
8 coal passers at $2.74	21.92
1 boiler washer at $3.42	3.42
	$69.74
1 chief engineer at $6.85	6.85
3 asst. engineers at $5.48	16.44
9 oilers at 2.96	26.64
1 janitor at $2.47	2.47
1 laborer at $2.50	2.50
6/7 steamfitter at $5.50	4.70
6/7 steamfitter helper at $3.50	3.00
6/7 machinist at $5	4.28
	$66.88

The maximum number of boilers per fireman per watch is 1.2 and the maximum h.p. corresponding is 220. On the day watch there are 870 lbs. of coal hand fired per hour per fireman.

The total number of engine units is 4. The number of city pumping engines equivalent to the average number of units in service is 3.5; the average equivalent number of pumping engines per engineer per watch is 2.6; the average equivalent number of pumping engines per oiler per watch is 0.9. The ratio of the cost of coal to cost of labor is 1.04. The daily pay roll is $136.62. The average pay per man per day is $3.28, per hour is 41 cts. The actual engine h.p. per dollar of daily pay roll is 7.1.

Lake View Pumping Station. There are two 210 h.p. Scotch marine boilers erected in 1897, but not now in use, and four 250 h.p. Scotch marine boilers, with Hawley down draught furnaces, hand fired, erected in 1906.

There is one 90 h.p., 5,000,000 gal., horizontal, compound, Worthington engine, 89.4 ft. piston speed, 14.9 r.p.m., erected in 1885, and one 215 h.p., 12,000,000 gal., horizontal, compound, Gaskill engine, 105 ft. piston speed, 17.3 r.p.m., erected in 1888, and one 234 h.p., 13,000,000 gal. horizontal compound Gaskill engine, 105 ft. piston speed, 17.3 r.p.m., erected 1891, and one 251 h.p., 14,000,000 gal. horizontal, compound, Holly engine, 119 ft. piston speed, 17.8 r.p.m., erected 1898, and one 450 h.p., 25,000,000 gal., vertical, triple, Allis engine, 170 ft. piston speed, 25 r.p.m., erected 1909.

The total rated h.p. of the boilers is 1,000 and of the engines is 1,240. The average h.p. developed by the boilers is 750 and by the engines is 790, the load factors being 75% and 64% respectively.

The daily pay roll is as follows:

9 firemen at $2.96	$26.64
3 coal passers at $2.74	8.22
1 boiler washer at $3.42	3.42
	$38.28

1	chief engineer at $6.85	6.85
3	asst. engineers at $5.48	16.44
12	oilers at $2.96	35.52
1	janitor at $2.47	2.47
1	well tender at $2.74	2.74
1	laborer at $2.50	2.50
6/7	steamfitter at $5	4.70
6/7	machinist at $5	4.28
6/7	machinist helper at $3.20	2.74
		$78.24

The maximum number of boilers per fireman per watch is 1 and the maximum h.p. corresponding is 250. On the day watch there are 1,140 lbs. of coal hand fired per hour per fireman.

The total number of engine units is 5. The number of city pumping engines equivalent to the average number of units in service is 2.8; the average equivalent number of pumping engines per engineer per watch is 2.1; the average equivalent number of pumping engines per oiler per watch is 0.7. The ratio of the cost of coal to cost of labor is 0.77. The daily pay roll is $116.52. The average pay per man per day is $3.37, per hr. is 42 cts. The actual engine h.p. per dollar of daily pay roll is 6.8.

Springfield Avenue Pumping Station. There are six 200 h.p. Scotch marine boilers, with Hawley down draught furnaces, hand fired, erected in 1900, and two 250 h.p. Scotch marine boilers, with Hawley down draught furnaces, hand fired, erected in 1907.

There are three 420 h.p., 20,000,000 gal., vertical, triple, direct acting, Worthington engines, 144 ft. piston speed, 17.6 r.p.m., erected in 1900, and one 840 h.p., 40,000,000 gal., vertical, triple, direct acting, Worthington engine, 170 ft. piston speed, 16.7 r.p.m., erected in 1906.

The total rated h.p. of the boilers is 1,700 and of the engines is 2,100. The average h.p. developed by the boilers is 900 and by the engines is 1,442, the load factors being 53% and 69% respectively.

The daily pay roll is as follows:

12	firemen at $2.96	$35.52
7	coal passers at $2.74	19.18
1	boiler washer at $3.42	3.42
6/7	hoist engineer at $5.60	4.80
		$62.92

1	chief engineer at $6.85	6.85
3	asst. engineers at $5.48	16.44
13	oilers at $2.96	38.48
1	janitor at $2.47	2.47
3	laborers at $2.50	7.50
6/7	steamfitter at $5.50	4.70
6/7	steamfitter helper at $3.50	3.00
6/7	machinist at $5	4.28
		$83.72

The maximum number of boilers per fireman per watch is 1 and the maximum h.p. corresponding is 225. On the day watch there are 1,190 lbs. of coal hand fired per hour per fireman.

The total number of engine units is 4. The number of city pumping engines equivalent to the average number of units in service is 5.2; the average equivalent number of pumping engines per engineer per watch is 3.9; the average equivalent number of pumping engines per oiler per watch is 1.2 The ratio of the cost of coal to cost of labor is 0.9. The daily pay roll is $146.64 The average pay per man per day is $3.30, per hour is 41 cts. The actual engine h.p. per dollar of daily pay roll is 9.8.

Central Park Avenue Pumping Station. There are six 200 h.p. and two 250 h.p. Scotch marine boilers, with Hawley down draught furnaces, hand fired, the former erected in 1899 and the latter in 1907.

There are three 405 h.p., 20,000,000 gal., vertical, triple, direct acting, Worthington engines, 144 ft. piston speed, 17.6 r.p.m., erected in 1900–01, and one 810 h.p., 40,000,000 gal., vertical, triple, direct acting, Worthington engine, 170 ft. piston speed, 16.7 r.p.m., erected in 1906.

The total rated h.p. of the boilers is 1,700 and of the engines is 2,025. The average h.p. developed by the boilers is 1,100 and by the engines 1,380, the load factors being 65% and 68% respectively.

The daily pay roll is as follows:

13 firemen at $2.96	$38.48
4 coal passers at $2.74	10.96
1 boiler washer at $3.42	3.42
1 conveyor engineer at $3.29	3.29
	$56.15
1 chief engineer at $6.85	$ 6.85
3 assistant engineers at $5.48	16.44
12 oilers at $2.96	35.52
1 janitor at $2.47	2.47
3 laborers at $2.50	7.50
6/7 steamfitter at $5.50	4.70
6/7 steamfitter helper at $3.50	3.00
6/7 machinist at $5	4.28
	$80.76

The maximum number of boilers per fireman per watch is 1.2, and the maximum h.p. corresponding is 254. On the day watch there are 1,062 lbs. of coal hand fired per hour per fireman.

The total number of engine units is 4. The number of city pumping engines equivalent to the average number of units in service is 5.2; the average equivalent number of pumping engines per engineer per watch is 3.9; the average equivalent number of pumping engines per oiler per watch is 1.3 The ratio of the cost of coal to cost of labor is 0.92. The daily pay roll is $136.91. The average pay per man per day is $3.29, per hour is 41 cts. The actual engine h.p. per dollar of daily pay roll is 10.1.

Harrison Street Pumping Station. There are two 340 h.p. B. & W. water tube boilers, with chain grates, hand fed to hopper, erected in 1906. There are two 282 h.p., 15,000,000 gal., vertical, triple, Allis engines, 159 ft. piston speed, 15.9 r.p.m., erected in 1889.

The total rated h.p. of the boilers is 680 and of the engines is 564. The average h.p. developed by the boilers is 340 and by the engines is 628, the load factors being 50% and 111% respectively.

The daily pay roll is as follows:

3 firemen at $2.96	$ 8.88
3 coal passers at $2.74	8.22
1 boiler washer at $3.42	3.42
	$20.52
1 chief engineer at $6.85	$ 6.85
3 assistant engineers at $5.48	16.44
6 oilers at $2.96	17.76
1 janitor at $2.47	2.47
1 well tender at $2.74	2.74
6/7 steamfitter at $5.50	4.70
6/7 steamfitter helper at $3.50	3.00
6/7 machinist at $5	4.28
	$58.24

The maximum number of boilers per fireman per watch is 1 and the maximum h.p. corresponding is 340. On the day watch there are 2,160 lbs. of coal gravity fired per hour per fireman.

The total number of engine units is 2. The number of city pumping engines equivalent to the average number of units in service is 2.3; the average equivalent number of pumping engines per engineer per watch is 1.7; the average equivalent number of pumping engines per oiler per watch is 1.15. The ratio of the cost of coal to cost of labor is 0.73. The daily pay roll is $78.76. The average pay per man per day is $3.65, per hr. is 46 cts. The actual engine h.p. per dollar of daily pay roll is 8.

Tests and Operating Costs of Two Oil-Fuel Pumping Plants. These notes were published in Engineering News, Aug. 20, 1908, and are from plants at Wrentham and Wareham, Mass.

The Wrentham plant includes 5.64 miles of 6, 8 and 10-in. cast-iron mains and 0.32 miles of 2-in. with steel standpipe, 30 ft. in diam. by 50 ft. high with adjacent oil-fuel pumping plant. The entire works cost about $50,000. The supply is from 2.5-in. tubular wells tapping a sandy, waterbearing, gravel stratum. The flow is such that the whole group of wells flows naturally when uncapped 1 ft. above the ground. The pumping station contains one room 25 by 36 ft. inside. The elevation of the floor being 5 ft. below ground level, the well water nearly floods the suction chamber of the pump. The equipment consisted of a 25 h.p., 12 by 12 in., two stroke cycle, horizontal, crude-oil engine (Mietz & Weiss), with a fuel oil tank and air compressor for starting. To this was geared an 8 by 10 in. Smith-Vaile pump, with actual ordinary use capacity of 250 U. S. gals. per min. at 90 r.p.m., against 130 lb. per sq. in. pressure. The test, of which the summary was given above, was made on Wednesday, March 4, 1908, under normal daily conditions of pumping, using ordinary fuel weighing 7.5 lbs. per gal. and costing about 5.75 cts. per gal. delivered at the pumping station, 1.5 miles from the freight station.

The works at Wareham include 5.4 miles of 6, 8 and 10-in. cast-iron mains, 34 fire hydrants, a steel stand-pipe 20 ft. by 100 ft. high and a double unit oil-fuel-engine pumping plant in the village of Tihonet. The supply is from 2.5 in. tubular wells, the combined yield of six of which during a steam-pumping test covering 85.5 continuous hrs. was at the rate of 315,000 gals. per day. The pumping station building is almost exactly like that at Wrentham.

TABLE XXXV. SUMMARY OF TEST ON OIL FUEL PUMPING PLANTS. WRENTHAM AND WAREHAM, MASS.

	*Wrentham	†Wareham	
	Single unit	North unit	South unit
Length test hours	6	3.5	3.5
Total No. revolutions	14,616	8,460	8,063
Average r.p.m	40.6	40.3	38.4
Average capacity pump gals. per min.	262.28	260.34	248.06
Total gals. pumped	94,419.36	54,651.6	52,087.0
Lbs. per cu. ft. at 48 and 49 deg. F.	62.41	62.40	62.40
Average pressure, lbs. per sq. in., pumped against	77.625	102.0	102.0
Average vacuum, ins.	13.2	10.9	10.5
Total equivalent height, corrected	197.88	249.86	249.33
Equivalent pressure for total height, lbs. per sq. in.	85.88	108.44	108.21
Total work; pump; ft.-lbs.	155,888,912	133,915,544	108,339,314
Average pump, h.p.	13.122	16.44	15.63
Hp.-hrs. developed at pump	78.732	57.54	54.71
Total lbs. fuel oil	153.25	98.0	92.0
Lbs. fuel oil per h.p.-hr., based on h.p. at pump end	1.95	1.70	1.70
Cost pumping 1,000 gals., cents	2.06	1.67	1.65
Cost raising 1,000,000 gals. 1 ft., cents	10.4	6.7	6.6

* Wrentham test made under normal conditions.
† Wareham test made with force-main stop gate throttled to increase work done by engine.

TABLE XXXVI. RECORD OF PERFORMANCE. WAREHAM AND WRENTHAM, OIL-FUEL, PUMPING PLANTS. (May, 1908.)

	* Wrentham plant	* Wareham plant
Days operated	20	27
Days idle	11	4
Average pumping period	3 hrs., 34 mins.	2 hrs., 38 mins.
Total gals. pumped; basis of 1% slip.	1,132,968	1,106,268
Population supplied	900	1,000
Average daily consumption, gals. per capita	41	36

* Both plants operating under normal daily conditions.

Average per cent. of superintendent's and engineer's time at pumping sta., on basis of 9 hr. day, including Sundays	30.9	43.1
Gals. fuel for pumping	258	269
Gals. fuel for warming up	26	33
Gals. fuel chargeable to month	284	302
Cost of fuel oil	$17.04	$21.14
Gals. lubricating oil	3.0	4.3
Gals. cylinder oil	2.5	0.5
Average pressure, lbs. per sq. in., pumped against	88.7	64.5
Average ins. vacuum, suction main	12.6	10.2
Total equivalent height of lift, including correction for gage heights	221.76	162.52
Average gals. pumped per gal. fuel used in pumping alone	4,400	4,110
Average gals. pumped per gal. fuel, all uses	4,000	3,660
Average duty per 100 lbs. fuel for pumping alone	72,000,000	66,000,000
Average duty per 100 lbs. fuel, all uses	65,000,000	59,000,000
Average pump, h.p.	9.55	9.2

The pumping outfit consists of duplicate 25 h.p., 12 by 12 in. two-stroke cycle, horizontal crude-oil (Mietz & Weiss) engines, connected to two 8 by 10 in. vertical, triplex pumps (Smith-Vaile), A test on both units was made on April 21, 1908, using ordinary fuel oil weighing 7.5 lbs. per gal. and costing about 7 cts. per gal. delivered at the station.

Cost of a 64-h. p. Gasoline Pumping Plant and Pumping. P. E. Harroun in the Transactions of the American Society of Civil Engineers, March, 1905, gives the following on the cost of a gasoline pumping plant for the water-works of Porterville, Cal., a city of 2,000 population:

Two gasoline engines:

Two gasoline engines, each 32 h.p.	$2,860
Hauling and placing on foundations	90
Two belt tighteners	76
Framing and placing same	22
Fittings, foundation bolts, tubes, etc.	48
Labor, lining up, adjusting, etc., 30 cts. per hr.	38
Belting	141
Miscellaneous	11
Cost of two engines in place	$3,286

Two pumps:

Two 9 x 12-in. single acting triplex pumps	$2,816
Hauling and placing on foundations	170
Foundation bolts, tubes and setting same	42
Special castings	372
Pipe, flanges and bolts	248
Valves	160
Fittings, gaskets, miscellaneous and blacksmithing	134
Labor connecting up	100
Ejector, pipe fittings and connecting up	38
Cost of two pumps	$4,080

This makes the combined cost of engines and pumps, exclusive of concrete foundations, $7,366.

The cost of pumping with this plant into a stand-pipe was as follows, in the month of May, 1904:

1,700 gals. crude Coalinga oil, at 4 cts.	$68.00
22 gals. engine oil, at 50 cts.	11.00
5 gals. engine gasoline, at 30 cts.	1.50
25 gals. pump oil, at 50 cts.	12.50
8 lbs. pump gear compounds, at 25 cts.......	2.00
20 lbs. waste, at 10 cts.	2.00
½ time of superintendent	50.00
Full time of assistant superintendent	65.00
Total per month	$212.00

During this month the pumps raised 12,678,000 gals. a height of 164 ft.; the pumps actually pumped 458 hrs. This makes the cost a trifle more than 10 cts. per million gallons raised 1 ft. high. There were 1,200 consumers who used 340 gals. per capita. The crude oil weighs 7.25 lbs. per gal., and develops 19,600 B.t.u. per gal. The best performance of the plant, extending over several days, has been 1.43 pints of crude oil per horse-power-hour. The combined efficiency of the pump and belting was 70%, so that 1 pint of crude oil developed about 1 b.h.p. per hr. Half of the superintendent's time is charged to the plant and half to the office expense of the water-works system.

Cost of Pumping with Gasoline and Cheaper Fuels Compared. C. R. Knowles (Engineering and Contracting, March 1, 1916), states that on the Illinois Central railroad in order to utilize the existing equipment many of the gasoline engines now in service have been converted to kerosene and distillate engines by the addition of attachments for pre-heating the oil to or near the flashing point before the oil enters the cylinder. These attachments consist of generators or mixing chambers wherein the oil is heated by the exhaust of the engine. They are made in various sizes and types, both for throttling and for hit and miss governors. With these attachments the engine is generally started on gasoline and is allowed to run on this fuel until the cylinder and generator are heated, when the oil is cut in. On other types a retort is provided where the oil is converted into a vapor or gas by heating the retort with a blow torch. Either method requires from five to ten minutes to start an engine running on oil. Electric ignition is used, as with gasoline engines. Very little carbon trouble is experienced with the use of these attachments and the lubrication required is about the same as with a gasoline engine.

A series of tests as recorded in the table of various fuels was made, pumping a total head of 61 ft., with an 8 x 10-in. single cylinder double acting pump direct connected to a 6-h.p. four-cycle horizontal gasoline engine equipped to run on kerosene and distillates as well as gasoline, controlled by a throttling governor. This engine was one of the first gasoline engines ever equipped to operate on low grade oils and has been continually operated on distillates from 36 degs. to 42 degs. Baume for the past six years.

TABLE XXXVII. EFFICIENCY OF VARIOUS GASOLINE ENGINE FUELS

Fuels used		
Distillate	40° Baumé	Flash, 150. Burn, 145.
Methyl alcohol	40.5° Baumé	Flash and burn at room temperature
Kerosene	46° Baumé	Flash, 124. Burn, 170.
Gasoline	62° Baumé	Flash and burn at room temperature
Motor spirits	58° Baumé	Flash and burn at room temperature

EFFICIENCY FUEL TESTS

	Distillate	Alcohol	Kerosene	Gasoline	Motor spirits
Pints per hour	6	7	6	7	6
Lbs. fuel per hour	5.145	6.062	4.943	5.373	4.755
Lbs. fuel per hp.-hr.	1.91	2.22	1.91	1.97	1.74
Pump, rev. per min.	43.35	43.32	43.54	43.72	43.79
Pumped, gal. per min.	175.	177.8	176.8	176.8	178.1
Cost of fuel per gal.	$0.04625	$0.40	$0.08	$0.15	$0.13
Cost of fuel per hour	.0347	.35	.06	.1313	.0975
Cost of fuel per hp.-hr.	.0129	.1282	.0220	.0483	.0356
Cost per 1,000 gal.	.0033	.0327	.0056	.0124	.0092
	Deg.	Deg.	Deg.	Deg.	Deg.
Temperature of cylinder start	165	90	135	46	46
Temperature of cylinder, run	145	145	145	130	125
Temperature of inlet air	110	125	120	60	60

The distillate is the most economical of the fuels used. The cost per water horse-power being 53% of the cost of pumping with kerosene, and only 27% of the cost of pumping with gasoline. The high cost of alcohol eliminates it as a fuel for pumping water and the result of the test is merely submitted as a comparative feature. No doubt better results could have been obtained by reducing the area of the combustion chamber as more compression is required to secure economical results from the use of alcohol in internal combustion engines. The power obtained from the use of kerosene was practically the same as from the distillate, the only difference being in the price of the two fuels. The gasoline test shows such results as might be obtained from the average gasoline engine under the same conditions. The fuel known as motor spirits, which has been widely advertised as a substitute for gasoline, operates under practically the same conditions as gasoline. An objectionable feature of this oil is a disagreeable odor and it would perhaps be undesirable to use in certain localities.

Cost of Diesel Engine Pumping in a Municipal Water Works. H. H. Gochnauer (Engineering Record, June 3, 1916), states that Diesel oil engines, operated for the year ended April 1, 1916, furnished power for the municipal water supply of Appleton, Wis., a city of 18,000 inhabitants, at an average fuel cost of $2.82 per million gallons of water pumped against a head of 185 ft. The installation consists of two 225-brake horsepower, three-cylinder, four-stroke cycle (Busch-Sulzer Bros.) Diesel oil engines, located opposite and parallel to each other in such a manner that their air compressors can be belted to either unit. Each engine is directly

TABLE XXXVIII. YEARLY COST OF DIESEL ENGINE OPERATION (1915–6)

	Total cost	Cost per million gallons
Fuel oil:		
44,610 gal. at 3.6 cts. per gal.	$1,605.96	$2.82
Lubricating oil:		
Cylinder, 559.50 gal. at 30 ct.	$167.85	
Air compress, 33.23 gal. at 30 ct.	9.97	
Engine, 109.46 gal. at 20 ct.	21.89	
Kerosene, 80.53 gal. at 8ct.	6.44	.36
Labor:		
Chief engineer	$1,350.00	
Three assistant engineers	2,340.00	6.48
Materials:		
Miscellaneous supplies and expenses (heating, telephone, stationery, printing, packing, etc.)	$887.95	
Maintenance of engines (repair exhaust pipe)	22.64	
Maintenance of pumps	215.95	1.98
Total operating cost	$6,628.65	$11.64

NOTE.— A break in the strainer system of the filter plant caused sand to be admitted into the cylinders of the pumps. One cylinder was so badly cut that it was necessary to reline it. The cost of this repair and the expressage on same constitute the pump maintenance.

connected to two Deane double-acting triplex pumps of 2,000,000 gal. capacity each, located one on each end of the engine shaft. The total capacity of one unit, 4,000,000 gals., is sufficient for the city's fire protection. By running the two units alternately, one each week, one unit is always in reserve.

Table XXXVIII gives the cost of operation of the Appleton pumping station from April 1, 1915, to April 1, 1916.

Concrete Muffler and Operating Cost of a Small Diesel Engine Pumping Plant. Deep-well pumps, a lighting system and commercial motors are supplied in the village of Downer's Grove, Ill., by a municipal electric plant consisting of two horizontal two-cycle 120-h.p. Snow Diesel engines. To cut down the noise of the exhaust the original mufflers were replaced by large reinforced-concrete mufflers designed by H. A. Gardiner, superintendent. They have conical roofs and a steel stack projecting 3 ft. above the top. The outside diameter is 8 ft. and the height 10 ft. The structure rests on six concrete piles, because if set on a solid foundation the ground in the vicinity starts vibrating in harmony with the exhaust. The size of the mufflers was determined by the piston displacement and scavenger air volume per stroke. The exhaust enters at the bottom and on the side, where a circular brickwork makes the gases whirl about the center of the muffler. This circular motion has a tendency to pull a vacuum behind the gases. On top of the brickwork forming the first stage is a system of grate bars, and on top of these are ordinary brick in loose layers which act as a baffle to break up the noise of the exhaust. On top of this is a fine wire screen with a layer of crushed stone to further break up the report. The conical-shaped top is merely to keep out the rain. A connection to the sewer is made to drain the interior condensation.

In order to keep the concrete from getting too hot when running continuously under heavy load, a .5-in. pipe is tapped into the exhaust pipe just outside of the muffler. Water is thus carried into the muffler as steam and keeps the temperature down. Frequently an accumulation of carbon in the muffler will catch fire, but it is allowed to burn out until the concrete begins to get too hot, when water is turned on full in the small pipe to put out the fire. This process makes the muffler self-cleaning. The mufflers are so effective that the exhaust cannot be heard or any vibration of the air or ground felt when standing immediately beside them.

When both engines are running their intakes exhaust about 4000 cu. ft. of air per minute from the room. After the installation was made it was found to be practically impossible to keep the engine room warm enough in winter. This was ingeniously overcome by making an air intake to the room and at the same time utilizing a portion of the waste heat of the exhaust. The iron exhaust pipe on one side of the station was bricked in, leaving about a 6-in. space around the pipe and with the outer end of the brickwork open. The inner end of this brickwork opens into the floor of the engine room near the intake ports of the engine. The air is thus drawn in over the hot exhaust pipe. The advantage is two-

fold — the warmed air produces a better mixture for the cylinders and gives the needed warmth for the engine room.

The exhaust pipe from the other engine is carried through the oil-tank room and the whole room is used as an intake flue for the engine. Incidentally this heat in the oil-tank room keeps the oil in good shape in the coldest weather.

Water Supply Provided by Deep Wells

The village water requirements are supplied from two deep wells, and in order that the pumping could be done entirely by electrical means a spcial type of deep-well pump, manufactured by the Deming Company, was used. These two deep-well pumps are belt driven by 15-h.p. variable-speed motors. These were the first pumps of the kind to be installed and their operation is considered very satisfactory. During peak load on the electric system the deep-well pumps are slowed down to the bare requirements of the system. They discharge into a 60,000-gal. cistern from which the water is supplied under 60-lb. pressure to the mains and standpipe by two centrifugal, two-stage, 350-gal.-per-minute pumps, driven by 20-h.p. variable-speed motors, which are also slowed down during peak-load periods.

Scalped oil is purchased in 10,000-gal. lots from the Texas Company and stored in the 12,000-gal. tank in the station. The average fuel cost for the year 1915, placed in the tank at Downer's Grove, was 2.94 cents per gallon. The average cost of oil at the switchboard for the same period, including that used in trial runs, testing out, tuning up, etc., was 0.331 cent per kilowatt-hour. The oil consumption was found on test to be 0.50 lb. of oil per brake horsepower-hour full load; 0.52 lb. of oil per brake horsepower-hour three-quarters load, and 0.60 lb. of oil per brake horsepower-hour one-half load, for oil having a heat value of 19,000 B.t.u. per pound. The over-all efficiency of the station is above 30 per cent.

Comparative Cost of Pumping Water by Steam and Producer Gas in a Municipal Pumping Plant. Thomas E. Butterfield (Power, May 2, 1911), has given the following figures for the municipal plant of Haddonfield, N. J. The water is taken from four artesian wells about 220 ft. deep. From each well a 6-in. branch leads to a 12-in. main extending from the well field to a water-tight concrete cistern 20 ft. in diameter and 42 ft. deep, the 12-in. main extending about 30 ft. down into this cistern, water being siphoned out of the wells as soon as the pumps lower the water level in the cistern.

Table XXXIX gives the daily expense with a rate of pumping of 1,000,000 gals. per day.

In making the comparison, data from steam pumping plants of similar size have been utilized to determine the cost of operation. The actual prices bid for a steam plant were used in determining the charges for interest, depreciation, sinking fund, etc. It should be understood, however, that the figures given do not represent the cost of operating the whole system because, with the exception of

TABLE XXXIX. COST OF PUMPING BY STEAM AND GAS

	Steam plant	Producer gas plant
Interest on cost of building and contents for one day, rate 4½%	$ 2.20	$ 2.85
Daily average charge for repairs and maintenance	0.35	0.41
Daily debit to sinking fund, interest at 4%, based on complete renewal in forty years	0.48	0.68
Daily cost of operation:		
(*a*) Labor: two men, 12 hours each, at $80 and $75 per month	5.10	5.10
(*b*) Fuel at $3.50 per ton	9.45	2.13
(*c*) Oil	0.20	0.25
(*d*) Waste	0.02	0.02
(*e*) Light (oil)	0.10	0.10
(*f*) Miscellaneous	0.20	0.20
Total daily expense	$18.10	$11.74

Estimated cost of pumping 1000 gallons water by steam 1.81 cts.
Estimated cost of pumping 1000 gallons water by gas.. 1.17 cts.
Estimated saving per 1,000,000 gallons water pumped.... $6.36

the building and contents, no charges are made for interest, maintenance, depreciation and sinking fund for the general system. Office expenses, improvements, etc., are likewise not included, as these charges would remain the same with either gas or steam as the source of power. The cost of constructing the gas-power plant as compared with a steam plant of similar size, however, has been taken into consideration.

Cost of Installing and Operating Pumps in a Small Waterworks. W. E. Housman (Engineering News, May 7, 1914), gives the following comparative costs of installing and operating 3 pumping units.

TWO 10-IN. SIMPLE DUPLEX STEAM PUMPS

Two pumps, delivered and erected	$ 3,200
Foundationes	350
Two 80-hp. return-tubular boilers bricked-in and erected on foundations with steel stacks	2,220
One 150-hp. feed heater and two feed pumps	450
Steam and exhaust piping, covered and erected	850
Brick building (27 x 58 ft.)	3,700
Total	$10,770

TWO TANDEM-COMPOUND DIRECT-ACTING STEAM PUMPS

In this estimate the increased cost of the pump is about offset by the decreased boiler capacity required and the building would be the same, hence the estimate of..........$10,770

TWO 600-GAL. TRIPLEX PUMPS

Two pumps with motor and starting apparatus	$4,300
Foundations	550
Wiring and erection	500
Building (30 x 26 ft.)	1,400
Total	$6,750

TWO 600-GAL. CENTRIFUGAL PUMPS

Two pumps with motor and starting apparatus	$2,100
Foundations	250
Wiring and erection	400
Building (24 x 28 ft.)	1,200
Total	$4,250

To obtain the coal required, the assumed steam consumption multiplied by the hydraulic h.p. and divided by 34.5 gives the boiler-h.p.-load. With a 4.5-lb. (per boiler h.p.-hr.) rate and a liberal amount for banking the estimated figures result. This coal rate is excessive for a large and very good plant using good coal; it should be increased for a poor plant and poor coal but may be decreased for very good coal. Moreover, the steam consumption given would be materially increased for old pumps in bad repair or units with poorly adjusted valves.

ESTIMATED OPERATING CHARGES FOR SMALL WATER WORKS PUMP INSTALLATIONS.

	Duplex steam pump	Triplex	Centrifugal
Efficiency of pump, per cent. (not including 10% slip loss, etc.):			
Pumping into mains	.....	60	47
Pumping into standpipe	.....	47	52
Steam, lbs. per water h.p. (includ. 10% slip loss, etc.):			
Pumping into mains	80	.....	.....
Pumping into standpipe	60	.....	.....
Cost of installation:			
Pumping into mains	$10,770	$6,750	$4,250
Pumping into standpipe	10,770	6,750	4,250
Cost per year of electric current at 3½ cts. per kw-hr.:			
Pumping into mains	.....	8,380	5,351
Pumping into standpipe	.....	4,190	4,843
Cost per year of coal at $2.50 per ton:			
Pumping into mains	1,506	.....	.....
Pumping into standpipe	1,369	.....	.....
Interest and depreciation at 12½%:			
Pumping into mains	1,346	844	531
Pumping into standpipe	1,243	844	531
Oil, waste and repairs	215	135	65
Total yearly charge:			
Pumping into mains	3,067	9,359	5,947
Pumping into standpipe	2,827	5,169	5,439

A Water Pumping Diagram. Frank Richards (Compressed Air, May, 1913), gives the diagram here presented, which may be found convenient for ready reference in water pumping comparisons or in preliminary estimates of pumping requirements. It represents

throughout the theoretical h.p., or 100% efficiency, in pumping different numbers of gals. per min. to different heights, up to 1,000 ft.

The weight of the gallon being taken as 8.34 lbs. the statement would be: Number of gallons per minute, multiplied by 8.34

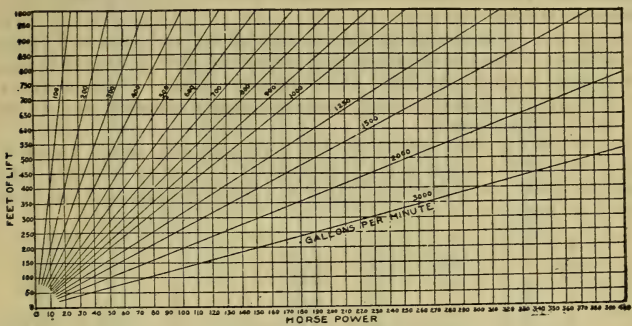


Fig. 2. Theoretical diagram of power required for lifting water.

pounds, multiplied by height of lift in feet, divided by 33,000 ft.-lbs., equals h.p.

Thus 500 gals. x 8.34 x 800 ft. of lift ÷ 33,000 = 101 h.p., as shown on the diagram.

Efficiency Test of an Air Lift Pump. In testing a Talbot air lift pump in Camden, N. J., L. T. Edwards (Engineering and Contracting, Aug. 9, 1916), states that the air was measured with a

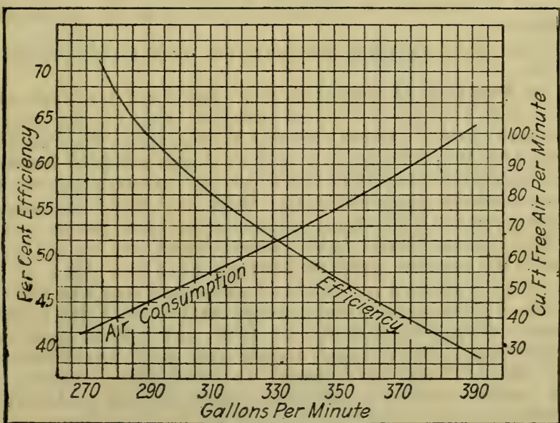


Fig. 3. Diagram of air lift pump efficiency.

General Electric air flow meter, and the water was measured by pumping into a 1,000-gal. tank for an interval of time measured with stop watches. The accompanying curves were plotted from the table. The normal output of the well was about 300 gals. per minute and the efficiency at this point was very nearly 60%. This efficiency is over all from the steam end of the compressor. Fifteen per cent. was added to the theoretical air horsepower to allow for friction. The curves show that when the well is forced beyond the normal output, the efficiency falls off rapidly. This is due to the increase of water friction with the higher velocity and to the decreased submergence.

The following data relate to the well and the test: Depth of well, 120 ft.; diameter, 8 ins.; surface to foot-piece, 106 ft.; foot-piece to point of discharge, 115.5 ft.; eduction pipe, 5 ins.; air pipe, 1.25 ins.

Cu. ft. free air per min.	Gal. per min.	Static pres.	Pres. at well top.	Cu. ft. air per gal.	Submergence, per cent.	Lift in ft.	Water, hp.	Air, hp.	Efficiency, per cent.
50	300	31.5	35.3	.166	63	42.8	3.22	5.40	59.6
60	322	31.0	35.5	.186	62	43.9	3.56	6.54	54.2
100	392	27.5	37.5	.255	55	52.0	4.55	11.30	40.2

Cost of Pumping Machinery and Reservoirs for Small Water Works. W. S. Johnson (Engineering and Contracting, Sept. 30, 1914), gives the cost of several small pumping plants of municipally owned water works in Massachusetts.

The cost of buildings for this machinery is given in the chapter on Buildings.

The costs of distributing reservoirs for these plants are given in Table XLI.

Cost of Pumping at Scranton, Pa. The total pumpage of the Maiden Creek pumping station of Scranton, Pa., for one year was 2,259,191,840 gals., without allowance for slip. The station is equipped with Worthington and Allis-Chalmers pumping machinery. Bituminous coal costing $2.65 per gross ton delivered was used and 6,022,100 lbs. were consumed during the year. The wood used cost $3.50 per cord, and an amount equivalent to 1,800 lbs. of coal was used. The average static head against which the pumps worked was 212.6 ft., and the average dynamic head was 291.8 ft. The number of gals. pumped per pound of equivalent coal was 375. The total cost of maintaining the pumping station was $13,301.91, or $5.89 per million gals. pumped, or 2 cts. per million gals. raised 1 ft. (dynamic). The principal items in the station expenses were: Coal, $7,129.83; oiling and packing, $1,010.73; firing boilers, $967; running engines, $907.54; unloading and stacking coal, $601.76; superintendence and general work, $528.43; oil and grease, $603.86; tools and supplies, $354.70; watching, $300.74.

TABLE XL. COST OF MACHINERY FOR SMALL WATER-WORKS IN MASSACHUSETTS

Town	Population	Pumps	Engines	Cost	Cost per horsepower
Ashland	1,682	2- 7 x 8	2-18 h.p. oil	$4,358	$121.00
Bedford	1,231	2- 8½ x 10	2-25 h.p. gasoline	4,000	80.00
Deerfield	....	1- 4 x 6	1- 7½ h.p. motor	475	63.30
Dracut	3,461	1- 8 x 10	1-20 h.p. gasoline	1,783	89.15
Dudley	4,267	2- 8 x 10	2-25 h.p. motors	2,500	50.00
East Brookfield	....	2- 5½ x 8	2- 8 h.p. oil	3,100	193.75
East Douglass	2,152	1-10 x 10 1- 7¼ x 10	1-35 h.p. motor 1-15 h.p. motor	2,455	49.10
Leicester	....	2- 8 x 10	2-18 h.p. oil	4,414	122.50
Littleton	1,229	1- 7½ x 10	1-25 h.p. oil	3,960	158.50
Marion	1,460	2- 7½ x 8*	2-40 h.p. oil	8,157	102.00
North Chelmsford	5,010	2- 7¼ x 10	2-25 h.p. motors	3,500	70.00
Pepperell	2,953	2- 8 x 10	2-25 h.p. oil	6,200	124.00
South Hadley	....	2- 8 x 10	2-35 h.p. oil	6,875	98.25
Wareham	....	2- 8 x 10	2-25 h.p. oil	5,642	112.80
West Groton	....	1- 6 x 8	1-10 h.p. gasoline	1,163	116.30
Wrentham	1,743	1- 8 x 10	1-25 h.p. oil	2,821	112.80
Wrentham State School	....	2- 6 x 8	2-10 h.p. motors	1,784	89.20

* Double acting.

NOTE.— All pumps are vertical, single-acting, triplex pumps, unless otherwise noted.

TABLE XLI. COST OF DISTRIBUTING RESERVOIRS FOR SMALL WATER-WORKS IN MASSACHUSETTS

Town	Kind.	Size, diam., height.	Capacity, gals.	Cost of foundation.	Cost including foundations.	Cost per 1,000 gals.
Ashland	Concrete standpipe	40 x 32	300,000	....	$5,812	$19.35
Bedford	Steel standpipe	20 x 100	235,000	$1,030	6,640	28.25
Dracut	Reservoir	......	225,000		2,385	10.60
Dudley	Reservoir	71 x 26	770,000	....	20,232	26.20
East Brookfield	Steel standpipe	25 x 50	184,000	300	3,550	19.30
East Douglass	Concrete standpipe	45 x 18	214,000	....	4,524	21.15
Leicester (Cherry Valley and Rochdale)	Concrete standpipe	40 x 21	197,000	....	4.976	25.25
Littleton	Steel standpipe	35 x 40	288,000	700	4,638	16.10
Marion	Steel standpipe	20 x 100	235,000	....	5,883*	25.00*
North Chelmsford	Steel standpipe	22 x 125	355,000	....	9,772	27.50
Oxford	Steel standpipe	27 x 50	214,000	400	5,060	23.60
Pepperell	Steel standpipe	45 x 40	476,000	839	6,707	14.10
Plainville	Steel standpipe	25 x 67	246,000	710	4,979	20.25
So. Hadley (Fire dist. No. 2)	Steel standpipe	35 x 60	432,000	....	6,165*	14.30*
Wareham	Steel standpipe	20 x 100	235,000	....	6,835*	29.10*
West Groton	Steel standpipe	30 x 40	212,000	613	4,021	18.95
Wrentham	Steel standpipe	30 x 50	264,000	800	6,000	22.70
Wrentham State School	Steel standpipe	22 x 50	142,000	368	2,596	18.25

* Without foundation.

Cost of Pumping at Two River Flushing Stations, Milwaukee, Wis. At Milwaukee, Wis., three rivers join and enter Lake Michigan. Two of the rivers, the Milwaukee, which flows south parallel to the lake shore, and the Kinnickinnic, which flows north and also parallel to the lake shore, are constantly being flushed out by means of pumping lake water into them some distance above their mouth. The tunnels supplying the water from the lake are each 12 ft. in diameter. The Milwaukee tunnel is 2,534 ft. long and the Kinnickinnic tunnel is 7,185 ft. long. The pumping plants are each of the same capacity, rated at 500 cu. ft. per sec.

The Milwaukee river flushing station is located at the lake end of the tunnel and is equipped with an E. P. Allis vertical tandem screw pumping engine and four return tubular boilers, 54 ins. x 16 ft., with down draft furnace.

The Kinnickinnic pumping station is located at the river end of the flushing tunnel. It is equipped with an Allis-Chalmers vertical tandem screw pumping engine and two horizontal tubular boilers, 72 ins. x 18 ft., with down draft furnaces.

The data on the operation of these plants for the year 1909 are as follows:

	Milwaukee River	Kinnickinnic River
Total million gals. displaced	114,306	90,519
Av. dynamic head pumped against, ft.	2.78	3.02
Av. steam pressure, lbs.	95	140
Coal consumed when pumping, tons	2,207	1.694
Grade of coal, screenings	Youghiogheny	Youghiogheny
Coal consumed per million foot, gals.	13.89	12.15
Ft.-lbs. of work per 100 lbs. of coal	58.523.230	68,887.288
Coal used for starting fires, lbs.	176.550	97,150
Coal used for all purposes, tons	2,295.7	1,742.8
Per cent. of ash	11.92	13.94
Cost of coal per ton	$2.405	$2.265
Cost of operation:		
Salaries	$11,940.00	$13,732.17
Coal	6,653.76	4,877.53
Total cost	$21,627.80	$19,542.52
Cost per million ft.-gals.	$0.068	$0.089

Cost of Pumping Water by Gasoline, Kerosene and Steam Pumps for Railway Water Supply.

(Abstract of committee report at the annual convention of the Association of Railway Superintendents of Bridges and Buildings.)

Chicago & Eastern Illinois R. R. A. S. Markley gives the following results of tests made to determine the cost of pumping at several of the water stations on this road. The results from the steam plant are given merely for comparison.

Chicago & Northwestern Ry. The data in the table are given by A. W. Merrick as showing the cost of pumping by gasoline power.

St. Louis & Southwestern Ry. J. S. Berry gives the cost of pumping as follows, using an 8-h.p., gear burr (Fairbanks, Morse & Co.) combination outfit:

Suction, size, ins.	4
Suction, lift, ft.	8
Discharge, horizontal, size, ins.	4
Discharge, horizontal, distance, ft.	100
Discharge, vertical, size, ins.	4
Discharge, vertical, distance, ft.	30

Cost—

Per 1,000 gals., gasoline	$0.1700
Per 1,000 gals., coal	0.0335
Per 1,000 gals., labor	0.0420
Gasoline, per gallon	0.1700
Coal, per ton	2.90

Pennsylvania Lines West of Pittsburg. The following data are given by A. F. Miller:

Cost of pumping water per 1,000 gals., gasoline	$0.00625
Cost of pumping water per 1,000 gals., coal	0.0125
Cost of pumping water per 1,000 gals., labor, gasoline	0.02
Cost of pumping water per 1,000 gals. labor, coal	0.05
Cost of gasoline per gallon	0.10
Cost of coal per ton	2.50

TABLE XLII. COST OF PUMPING WATER AT WATER STATIONS CHICAGO & EASTERN ILLINOIS R. R.

Water station.	Oxford.	Winthrop.	Tramms.
Date	Oct., 1900	Oct., 1900	1901
Make of engine	Stewart	Stewart	Stickney
Size of engine, ins.	6 x 10	6 x 10	....
Make of pump	Stewart	Stewart	Stickney
Size of pump, ins.	6 x 10	5 x 10	....
Vertical section, ft.	15	15	20
Horizontal suction, ft.	30	30	15
Size of suction pipe, ins.	4	4	6
Vertical discharge, ft.	45	45	45
Horizontal discharge, ft.	250	75	125
Size of discharge pipe, ins.	4	4	6
Period of test	3 days	5 days	426 days
Fuel	Pick-up coal	Mine-run coal	Gasoline
Amount of fuel (gals. or lbs.)	760	1470	615
Water pumped, gals	47,620	125,093	4,836,000
Fuel per 1,000 gals. water (gal. or lb.)	15.9	11.75	0.13
Cost of fuel (gal. or ton)	$0.08	$1.80	$0.10
Wages of pumper, per month	17.50	17.50	10.00
Cost ignitor battery per 1,000 gals. water	....	....	$0.0011
Cost of fuel per 1,000 gals. water	$0.00638	$0.0106	$0.013
Cost of labor per 1,000 gals. water	$0.0362	$0.0229	$0.028
Total cost per 1,000 gals. water	$0.04258	$0.0335	$0.0421

Kind of pump, size and h.p.: Combined gasoline, 8-in. piston, 8-in. stroke, 5-h.p. Steam, 10 x 7 x 10 in. (Blake).

Suction, size and lift: Gasoline, 6-ft. suction, size 6 ins., 10 ft. lift. Steam, suction 5 ins., increased to 6 ins. at pump, lift 12 ft., distance horizontally 70 ft.

Discharge, horizontal distance and size: Gasoline, discharge 5 ins. increased to 6 ins. at pump, distance 35 ft. Steam, discharge 4 ins. increased to 6 ins. at pump, distance 50 ft.

TABLE XLIII. COST OF PUMPING WATER PER 1,000 GALLONS BY GASOLINE POWER. (NOT INCLUDING REPAIRS)

	C. & N. W. Ry., 1903			C. & E. I. R. R., 1899		
	Richmond, Ill.	Normandy, Ill.	Buda, Ill.	Bourbon, Ill.	Clinton Ill.	Wellington, Ill.
Kind of engine	3½ h.p. Otto	10 h.p. Otto	10 h.p. Otto	6 h.p. Otto	10 h.p. Otto	F. M. & C., 3 h.p. Comb
Speed of engine, revs.	390	300	312			
Kind of pump	5 x 6 in. Deming	16 in. Strk. Curtis	16 in. Strk. Curtis	5 x 18 in. Curtis	6 x 18 in. Curtis	Combination Eng. and Pump
Strokes per minute	80	40	44	....	....	
Size of suction, ins.	3	4	4	....	....	....
Size of discharge, ins.	2½	4	4	....	....	....
Distance pump to tank, ft.	860	50	1600	2,600	1,000	300
Height pump to top of tank, ft.	44	44	44	40	63	35
Height pump above water, ft.	9	3	2	10 to 25	13	10 to 25
Time of test	13 hrs. 15 min.	1 hr. 20 min.	2 hrs. 18 min.	6 hrs.	4 hrs.	131 hrs.
Total gals. pumped	21,664	11,314	20,131	26,995	36,180	532,560
Gals. gasoline used	.....	.....	.....	2.9	2.25	55.37
Pumper's wages	$0.36	$0.15	$0.26	$10.00 per month	$10.00 per month	$10.00 per month
Cost gasoline per 1,000 gals. water	$0.0115	$0.0114	$0.0094	$0.01075	$0.00741	$0.01040
Cost labor per 1,000 gals. water	$0.0166	$0.0133	$0.0129	$0.01196	$0.00960	$0.01088
Total cost per 1,000 gals. water	$0.0281	$0.0247	$0.0223	$0.02271	$0.01710	$0.02128

Discharge, vertical distance and size: Gasoline, discharge 6 ins., distance 35 ft. Steam, discharge 6 ins., distance 36 ft.

The difference in cost of labor per thousand gallons of water between coal and gasoline is explained as lying in salary of pumper, the man using coal receiving $33 per month and the man using gasoline receiving $5 per month.

Lake Superior & Ishpeming Ry. The following data are given by A. Anderson:

Total cost of pumping for 1907:

	Whitefish tank	Slapneck tank
Labor, pumping	$117.08	$187.91
Keeping fire under tank	49.26	57.00
Coal for fire under tank	19.37	19.37
Gasoline	53.61	45.93
Oil and waste	4.62	6.26
Repairs to engine	48.59	72.59
Repairs, buildings or tanks	36.67	169.39
Cost of all labor and material	$329.20	$558.45
No. gals. water pumped during year	2,176,000	3,208,500

In explanation of these figures Mr. Anderson says the above statement is a record kept of pumping and repair costs at two of our principal water stations for the year 1907, and represents a year's maintenance and operation. The gasoline cost per 1,000 gals. of water is about $0.0187. A 3.5 h.p. gasoline engine was used at Whitefish and a 2.5 h.p. at Slapneck. The pumps and engines are located beneath tank. Fire is kept from about Nov. 1 to April to keep engines, pumps and water from freezing, using ordinary soft coal with station stoves, for this purpose.

Atchison, Topeka & Santa Fe. J. F. Parker gives the following statement:

We do not use on this division either gasoline, kerosene or coal. We have three plants where distillate is used and at the balance of our pumping plants we use oil for fuel. I have given you the cost for one gas engine plant, also for one plant where crude oil is used for fuel. The deep well pump and power head used at the distillate plants is, I believe, machinery that is used only on the Pacific coast.

The cost at the station using distillate is given by Mr. Parker as follows:

Cost of pumping water per 1,000 gals., distillate	$.039
Cost of pumping water, per 1,000 gals., labor	.015
Cost of distillate per gal.	.08

Kind of pump, size and horse power: Pomona deep well double-plunger pump, with No. 18 power head, operated by 10-h.p. West Coast gasoline engine.

Suction, size and lift: 6-in. suction, 80-ft. lift.

Discharge, horizontal distance and size: 4-in. discharge, distance 600 ft.

Discharge, vertical distance and size: 4-in. discharge, distance 27 ft.

TABLE XLIV. AVERAGE COST OF PUMPING WATER PER 100 GALLONS BY GASOLINE ENGINE POWER FOR SIX MONTHS, AUG., 1902, TO JAN., 1903, INCLUSIVE (NOT INCLUDING REPAIRS)

C. & N. W. Ry.	Consumption under 500,000 gals. per month		Consumption over 500,000 gals. per month	
Divisions	Gals. per month	Cost per 1,000 gals.	Gals per month	Cost per 1,000 gals.
Galena	334,000	$ .0760	1,532,000	$ .0413
Wisconsin	196,000	.0500	989,000	.0303
Iowa	......	....	15,320,000	.0200
Ashland	107,000	.1130	2,034,000	.0306
I. & M.	286,000	.0905	4,109,000	.0392
Average	......	$0.0824	....	$0.0323

Regarding the use of crude oil, Mr. Parker states:

Our pumping is done principally by steam pumps, using crude oil for fuel at 25 cts. per barrel of 42 gals. With this oil we are enabled to raise water 80 ft., including suction and discharge, at a cost of $.0015 for the oil per 1,000 gals. of water pumped and $.015 for labor, or a total of $.0165. At this crude oil plant, Victorville, we produced for the month 3,507,000 gals. of water at a cost of $77.50 for fuel, labor and maintenance, or an average of $.022 per 1,000 gals. of water.

Northern Pacific Ry. F. Ingalls furnishes the following data, where the cost of pumping with gasoline and coal are very nearly equal:

Cost of pumping water per 1,000 gals., gasoline ..	$0.0333
Cost of pumping water per 1,000 gals., coal	0.02
Cost of pumping water per 1,000 gals., labor, gas	0.0225
Cost of pumping water per 1,000 gals., labor, coal	0.039
Cost of gasoline per gal.	0.15
Cost of coal per ton (lignite coal used)	1.25

Kind of pump, size and horse power: 5 x 12-in. pump in steam plant. 20 h.p. gasoline engine, with Smith-Vaile deep well pump, in gasoline plant.

Suction, size and lift: 6-in. suction, 800 ft. long, with 12-ft. lift, in steam plant; 8-in. suction, 18-ft. lift, in gasoline plant.

Discharge, horizontal distance and size: 6-in. discharge, 100 ft. long, in steam plant; 6-in. discharge, 125 ft. long, in gasoline plant.

Discharge, vertical distance and size: 6-in. discharge, 32 ft. to bottom of tank in both plants.

Lake Erie & Western R. R. Penwell gives the following data:

"We have but few gasoline pumping stations. We have two small plants that are not considered in this report that are very expensive. My experience has been that if a small supply is required there is but little economy in gasoline outfits, but where a large supply is required we have found the gasoline economical. We have but four gasoline pumping stations and no kerosene plants."

The following table gives results of Mr. Penwell's tests:

Cost of pumping water per 1,000 gals., gasoline	$0.032
Cost of pumping water per 1,000 gals., coal	0.057
Cost of pumping water per 1,000 gals., labor	0.012
Cost of gasoline per gal.	0.11
Cost of coal per ton	2.50

Kind of pump, size and horse power: Fairbanks, Morse & Co., Duplex, 10 x 7 x 12 in., steam plant. Fairbanks, Morse & Co., 8 x 12 in., in gasoline plant.

Suction, size and lift: 6-in. suction, 15-ft. lift.

Discharge, horizontal distance and size: 6-in. discharge, 3,600 ft. long.

Discharge, vertical distance and size: 6-in. discharge, 50 ft. long.

Total Fixed Charges and Operating Costs of Rotatory Pumps Compared with Those of High-Duty, Vertical, Triple-Expansion Type. The following figures based on estimates were prepared by Walter O. Beyer, and published in Engineering Record, June 15, 1912.

CAPACITY 8,000,000 GAL. DAILY

Item.	350 ft. head vert. c. & f-w. triple-exp. 150,000,000 duty, three 125-h.p. boilers.	491 w.h.p. steam-turbine 105,000,000 duty, three 175-h.p. boilers.
Cost pump, unit	$72,000	$16,000
Int. and depr., 10%	7,200	1,600
Cost boilers	11,250	15,750
Int. and depr., 17%	1,915	2,680
Labor, 3 shifts, engines.......	2,700	2,700
Labor, 3 shifts, boilers	1,800	1,800
Total int., depr. and labor	13,615	8,780
Fuel cost, $2 per ton..........	7,467	10,700
Fuel cost, $3 per ton	11,129	16,100
Fuel cost, $4 per ton	14,934	21,400
Total annual cost, coal, at $2..	21,082	19,480
Total annual cost, coal, at $3..	24,744	24,880
Total annual cost, coal, at $4..	28,549	30,180

CAPACITY 20,000,000 GAL. DAILY

Item.	280 ft. head vert. c. & f-w., trip.-exp. 165,000,000 duty, three 225-h.p. boilers.	981 w.h.p. steam-turbine centrifugal 120,000,000 duty, three 300-h.p. boilers.
Cost pump, unit	$120,000	$26,000
Int. and depr., 10%	12,000	2,600
Cost boilers	20,250	27,000
Int. and depr., 17%	3,440	4,590
Labor, 3 shifts, engines	2,700	2,700
Labor, 3 shifts, boilers	1,800	1,800
Total int., depr. and labor	19,940	11,690
Fuel cost, $2 per ton	13,570	18,630
Fuel cost, $3 per ton	20,335	27,945
Fuel cost, $4 per ton	27,140	37,260
Total annual cost, coal, at $2..	33,510	30,320
Total annual cost, coal, at $3..	40,275	39,635
Total annual cost, coal at $4..	47,080	48,950

CAPACITY 40,000,000 GAL. DAILY

200-lb. steam pressure. Item.	300 ft. head 275 deg. superheat vert. c. & f-w., trip.-exp. 223,000,000 duty, three 350-h.p. boilers.	2120 w.h.p., 28.5-in. vac. steam turbine, centrifugal, 193,000,000 duty, three 400-h.p. boilers.
Cost pump	$210,000	$55,000
Int. and depr., 10%	21,000	5,500
Cost, boilers	31,500	36,000
Int. and depr., 17%	5,360	6,100
Labor, 3 shifts, engines	7,200	7,200
Labor, 3 shifts, boilers	5,320	5,320
Total int., depr. and labor	39,480	24,120
Fuel cost, coal, at $2	23,265	26,800
Fuel cost, coal, at $3	34,897	40,200
Fuel cost, coal, at $4	46,330	53,600
Total annual costs, coal, at $2.	62,475	50,920
Total annual costs, coal, at $3.	74,377	64,320
Total annual costs, coal, at $4.	85,810	77,720

The prices for pumping units are believed to be accurate and include condensers, piping and foundations complete.

No account has been taken of the greater volume required in the buildings for reciprocating units. However, the difference in cost of foundations has been taken into account, because this is an addition in existing buildings and can be computed easily. In a comparison of this kind certain assumptions must necessarily be made. All figures of first cost of apparatus have been taken from or estimated from recent (1912) bids on the two types of machinery under consideration. The first cost per boiler h.p. we have taken to be $30 complete with piping, chimney, stokers, etc. The use of a lower figure would favor the turbine-driven pump as compared with the high-duty engine, but we believe with everything taken into consideration this will prove to be an average figure. We have assumed the following annual charges against pumping machinery: Interest 5%; depreciation, 3%; repairs and supplies, 2%; total, 10%.

We have also assumed the following annual charges against the boiler equipment: Interest, 5%; depreciation, 5%; repairs and supplies, 5%; labor on maintenance, 2%; total, 17%.

It will be noted in the above that an annual depreciation of 3% has been taken on the first cost of both the crank-and-flywheel and turbine-driven unit, equivalent to a life of 33⅓ years. We have chosen this method rather than one in which the capital charges are figured on a constantly decreasing book value for the pumping machinery and boilers, in order to avoid a complicated method of accounting. For the reason that less data are available on the life of turbine-driven units than on crank-and-flywheel units, it is possible that some objection may be made to this assumption of a life of 33⅓ years for each machine. However, as in neither case the question of obsolescence has been taken into account, we believe the assumption a fair one.

It appears that the steam turbine has reached a stage of development such that improvements will appear only as refinements of type, and possibly steam economies can be reduced only suffi-

ciently to render obsolete the present good designs by better theoretical design and by better steam conditions. The use of high steam pressures and superheat may be expected to gradually obtain further favor in this country as in European practice, where 250 degs. Fahr. superheat and 200 lbs. steam pressure are not unusual. This, however, entails practically no change in turbines as constructed for present steam conditions.

Fuel costs are based on a boiler efficiency of 65% heat content of 13,000 B.t.u. per pound of coal and 24 hrs. per day operation. The duties given are on a basis of 150 lbs. steam pressure with no superheat. Three examples are taken based on coal at $2, $3 and $4 per ton. Where coal can be obtained cheaper than $2 per ton the advantages of the turbine-driven pump are more clearly marked.

It will be noted that the point at which the total annual costs are equal for the 8,000,000-gal. crank-and-flywheel vertical unit, and the 8,000,000 gals. turbine, centrifugal unit is when coal costs $2.91 per ton. Also for the 20,000,000 gal. vertical crank-and-flywheel unit, and the 20,000,000 gal. turbine centrifugal unit, the total annual costs will be equal when coal costs $3.25 per ton. Above these points the reciprocating unit has the advantage and below these points the rotatory unit has the advantage on the basis of these calculations.

We believe that it can be assumed safely that the development of pumping machinery in the future will be along somewhat the same lines as the development of power producing machinery. At the present time one of the most noticeable features in the development of power machinery is the increasing favor with which larger units are being adopted. In large central station work five years ago the ordinary size of unit was from 1,000 to 15,000 kws. Now, not only in European practice, but also in American practice, 25,000 kw. units are being installed in the large stations. There are two reasons for this development, the first being the continual endeavor to obtain better economy, not only in actual steam consumption, but in capital charges, including first cost, buildings, real estate, etc. The second reason for the development along this line comes from the fact that engineers of to-day seem to have more initiative than formerly and where before the development of a 15,000-kw. turbine would have seemed an impossible task, now the installation of 25,000-kw. turbines is becoming a matter of course.

We have assumed that there will be progress along this line in water-works pumping machinery and that installations of very large units will be made in the future. We have evolved a comparison between two units of the types under consideration, each having a capacity of 40,000,000 gals. per 24 hrs., against a total head of 300 ft. This comparison is based on utilizing the greatest range of steam temperature which the best modern practice has established as commercially practicable, and which at the same time is not too intensely theoretical. We refer here to European practice in which steam pressures of 200 lbs., 275 degs. Fahr. superheat, and 28.5-in. vacuum are successfully and commercially utilized. Especially important in this connection is the item of high

vacuum, since in the case of waterworks large quantities of water are always available for condensing purposes.

There is practically no development necessary on the turbine to take advantage of these conditions, as the turbine of almost exactly the same characteristics that would be necessary for this installation is now in successful operation in hundreds of power-producing plants to-day. We have had to assume no steam consumption, as this is a matter of test, and practically have had to assume no pump efficiencies, as we have taken the minimum, which we know can be obtained on this size pump.

It is apparent from these tables that the point at which the two curves of overall economy of the two units cross is at a cost of approximately $8.80 per ton for coal.

Cost of Operating a Small Municipal Pumping Plant. S. Scarth (Power, May 2, 1911), states that Newark, N. Y., a small town of about 6,000 inhabitants, has a direct-pressure system with a standpipe located at the highest point in the village. Water is pumped from a receiving basin fed by gravity from springs. The average suction lift is 20 ft. and the discharge head averages 160 ft.

The pumping station contains two horizontal return tubular boilers, 60 ins. by 16 ft. These are used alternately and are in fairly good condition considering their age, 24 years, and are allowed 85 lbs. pressure by one of the leading boiler insurance companies.

The pumps are Worthington direct acting, one a compound 12 and 18⅝ by 10¼ by 10 ins. in size and the other a simple 16 and 10¼ by 10 ins. (the latter is held in reserve for emergencies). There is one boiler-feed pump 5¾ and 3½ by 5 ins., delivering water through a Baragwanath heater to the boilers at a temperature of 210 degs.

Operating an average of 10 hrs. out of the 24 and, being subject to a fire call at any time, the plant has steam up with banked fires during the other 14 hrs. The night engineer reads the service meters monthly. Run-of-mine coal is used, which costs $2.95 per ton delivered in the coal bin.

The cost of operating the station for the year ending Feb. 28, 1911, was as follows (not including interest and depreciation):

310 tons coal at $2.95	$ 914.50
Oil and waste	11.50
Packing	13.25
Repairs	43.50
Engineer and assistant	1,083.50
	$2,066.25

In the year 86,836,900 gals. of water against an average total head of 180 ft. were delivered to the mains using 310 tons of coal. This shows the duty of the plant to be slightly over 21,000,000 ft.-lbs. of work per 100 lbs. of coal. The cost of pumping was, then, 2.379 cents per 1000 gals. delivered.

The water end of the pump showed an efficiency of 90%.

Cost of Oil Pumping in California. The following figures are taken from Technical Paper No. 70, Bureau of Mines, entitled

"Methods of Oil Recovery in California," to which the reader is referred for more complete information on the methods pursued.

VOLUMES OF NATURAL GAS REQUIRED TO OPERATE A GAS ENGINE OR TO SUPPLY A STEAM ENGINE PLANT USING GAS AS FUEL UNDER BOILERS. (After H. F. Oliphant.)

	Cubic feet per indicated h.p.-hr.
Large gas engine, highest type	9
Ordinary gas engine	13
Triple-expansion condensing steam engine	16
Double-expansion condensing steam engine	20
Single-cylinder steam engine with cut-ff	40
Ordinary high-pressure steam engine without cut-off	80
Steam engine ordinarily used for pumping oil wells	130

Methods of Generating and Distributing Power for Pumping Oil in the California Oil Fields in 1913. The following data are given:

No. of wells	6,223
Flowing	217
Compressed air	247
Gas engines:	
Beams	1,217
Jacks	1,042
Electricity:	
Beams	559
Jacks	310
Steam:	
Beams	2,095
Jacks	536

Data Relative to Cost of Well-Pumping Equipment. The following data are given:

DEPTH OF WELLS 800-FT. GRAVITY OF OIL + 0.875 (+ 15 DEGS. B). Santa Clara Valley District. (Data by W. R. Hamilton.)

Initial Cost of Installation.

Pumping power—

Station driving 17 wells, including cost of building, 20-h.p. gas engine, simplex power, belt, piping, jerker lines, labor — everything up to the derricks at the wells, but not including pumping jacks at wells, tubing or rods	$3,068.36
Cost per well	180.49

Cost of Operation and Maintenance.

Pumping. Cost, including wages of pumpers, all repairs and replacements for power plants and jack lines, lubricating oils, etc., but not including repairs to wells, depreciation of plants, or interest on investment, varied from 30 to 55 cts. a day per well, depending on the extent of the replacements necessary. An average for a long period would be about 43 cts.

DEPTH OF WELLS 1,000 ± FT. GRAVITY OF OIL ± 0.965 (± 15° B.).
Kern River Field.
Cost of Operation and Maintenance.

Steam engines. 50.8 cts. per barrel.
Air compressor. 2.4 cts. per barrel.

Remarks. The difference in cost is due to the increased production when compressed air is used.

DEPTH OF WELLS 1,000 ± FT. GRAVITY OF OIL ± 0.965 (± 15° B.).
Kern River Field.
Cost of Operation and Maintenance.

Steam engines. 20.24 cts. per barrel.
Pumping power. (Driven by electric motor) 18.28 cts. per barrel.
Remarks. The daily production per well was about 20 bbls.

DEPTH OF WELLS 1,000 ± FT. GRAVITY OF OIL ± 0.965 (± 15° B.).
(Kern River Field. Data by C. T. Hutchinson.)

Initial Cost and Cost of Installation.

Air compressors. Three plants, one with a capacity of 4,000 cu. ft. of free air and two with a capacity of 2,000 cu. ft. of air, $200,000.

Remarks. The first plant comprised two compressors each with a capacity of 2,000 cu. ft. of free air. Each compressor had a Corliss steam cylinder and twin-tandem air cylinders, and each machine required 650 h.p. when developing a pressure of about 150 lbs. per sq. in. There were five 207-h.p. water-tube boilers, one 75-kwt. electric-light plant, and two condensers.

Depth of Wells 1,000 ± Ft. Gravity of Oil 0.9722 (14° B.)
(Kern River Field. Data by Kern River Oil Fields.)
Cost of Operation and Maintenance for 48 Wells.

Steam engines:

Labor	$0.36
Repairs	.07
General expense	.03
Fuel oil (assuming price of 30 cts. per barrel)	.90
Water	.50
	$1.86

Electric motors:

Labor	$0.29
Repairs	.07
General expense	.03
Electric current	.56
Daily cost per well	$0.95

Depth of Wells 600 to 1,200 Ft. Gravity of Oil 0.9790 (13° B.).
(Midway Field. Data by R. S. Hazeltine for 12 wells in group.)
Initial Cost and Cost of Installation.

Electric motors:

New roof on engine houses	$240.00
Eleven 15 to 5 horsepower motors, One 20 to 6 horsepower motor, Three 25-kilowatt transformers,	6,670.00

Installation	$3,500.00
Counterbalance for beams	300.00
Discarded steam engines	1,000.00
Total	$11,710.00
Cost per well	$975.83

Cost of Operation and Maintenance.

Steam engines:	
Labor	$409.50
Fuel oil	523.20
Water	697.00
Repairs to boilers and engines	88.44
Oil waste and packing	97.42
Total	$1,815.56
Average daily cost per well	$5.09
Electric motors:	
Labor	$432.70
Electric equipment	390.27
Fuel oil	156.20
Water	349.89
Repairs to boilers and engines	22.30
Oil waste and packing	62.54
Total	$1,413.90
Average daily cost per well	$3.85

Remarks. Boiler water was purchased at 5 cts. per barrel and oil produced was contracted at 50 cts. per barrel.

DEPTH OF WELLS 900 TO 1,200 FT. GRAVITY OF OIL 0.9655 (15° B.).
(Kern River Field. Data by A. G. Crites.)

Initial Cost and Cost of Installation.

Steam engines:	
Corliss condensing engines, 320 and 420 h.p.	$69,050.93
Myers noncondensing cut-off engines	41,430.59
Electric motors:	
Electric driven plant, 420-h.p.	27,620.37
Gas engines:	
Included under air compressors.	
Air compressors:	
One 320-h.p., driven by Buckeye gas engine pipe lines, etc., complete	39,344.19
One 420-h.p., driven by Buckeye gas engine, complete	22,781.79

Cost of Operation and Maintenance.

Steam engines:	
Corliss —	
Interest for 1 year at 6%	$ 4,143.05
Depreciation for 1 year at 10%	6,905.09
Labor, 4 men at $100 per month	4,800.00
Repairs and incidentals (estimated)	1,800.00
Fuel oil, 23,005 bbls. at 35 cts. per barrel	8,051.75
Total for 1 year	$25,699.89
Myers—	
Interest for 1 year at 6%	$ 2,485.83
Depreciation for 1 year at 10%	4,143.05
Labor, 4 men at $90 per month	4,320.00

Repairs and incidentals (estimated)	$1,000.00
Fuel oil, 51,500 bbls. at 35 cts. per barrel	18,025.00
Total for 1 year	$29,973.88

Gas engines:

Included under air compressors.

Electric motors:

Interest at 6%	$ 1,657.22
Depreciation at 10%	2,762.03
Labor, 2 engines at $135 per month	3,240.00
Repairs and incidentals (estimated)	500.00
Power, 4,326,406 kw. at 1 ct. per kw.	43,264.06
Total for 1 year	$51,423.31

Air compressors:

One 320 h.p.—	
Interest for 10 months at 6%	$1,967.21
Depreciation for 10 months at 10%	3,278.68
Labor—	
One engineer, $150 per month	1,500.00
One engineer, $4.50 a day	1,363.50
Extra labor, repairs	82.00
Extra material for repairs	249.44
Oil, water, and incidentals	710.20
Total for 10 months	9,151.03

Remarks. Natural gas is recovered by the vacuum made by the gas engines, its value not being considered therefore.

Cost of power per h.p.-hr. was 0.00478 in 1910, 0.00488 in 1911, and 0.00260 in 1912.

DEPTH OF WELLS 1,850 TO 2,000 FT. GRAVITY OF OIL ± 0.952 (±17° B.).
(Coalinga Field. Data by Thomas Cox.)

Initial Cost and Cost of Installation.

Gas engines:

Installation, gas mains, traps, tail pumps, foundations, engines proper, belting, and engine houses	$1,260

Cost of Operation and Maintenance.

Steam engines:

Average total cost per well per month	$270
Average total cost per well per day	9

Gas engines:

Three men per tour (12 hours) to 19 wells	33
Two repair men	21
Lubricating oil per well per month	6
Repairs, power, and attendance per well per month	60
Repairs, power, and attendance per well per day	2

Remarks. Thirty and 45 h.p. engines. Five-inch water pressure. Magneto ignition.

DEPTH OF WELLS 1,600 TO 2,500 FT. GRAVITY OF OIL 0.9589 (16° B.).
(Coalinga Field. Data by Thomas Crumpton.)

Initial Cost and Cost of Installation.

Steam engines:

One 23-h.p. engine complete	$ 296.69
One 40-h.p. boiler	473.00

Boiler connections	$ 116.15
Engine house, 12 by 14 ft., blocks, lumber, labor, etc.	66.80
Total	$ 952.64

Gas engines:

One 30-h.p. engine and connections	$1,027.04
Engine house, 16 by 14 ft., cement foundation, including labor	250.13
Total	$1,277.17

Cost of Operation and Maintenance.

Steam engines:

Operation—	
2 pumpers, at $105 a month, for five engines	$ 42.00
10 gals. of steam-engine oil, at 19 cts.	1.90
14 gals. of cylinder oil, at 30 cts.	4.20
180 bbls. of fuel oil for boiler for well	90.00
Haulage of lubricating oil (labor and horse)	1.00
Maintenance—	
Labor and horse per month per well	3.10
Repairs of boilers per month per well	19.30
Average per well per month	$161.50
Average per well per day	$53.83

Gas engines:

Operation—	
2 pumpers, at $105 per month, for 11 engines	$19.09
13 gals. of engine oil, at 44 cents	5.72
4 gals. of engine oil, at 23 cents	.92
Haulage of oil (labor and horse)	1.50
Maintenance:	
Labor and horses, at $275 per month, for 50 engines	5.50
Repairs and renewals, at $88.95, for 50 engines, per month	1.78
Average per well per month	$34.51
Average per well per day	$1.15

DEPTH OF WELLS, 2,745 FEET. GRAVITY OF OIL $\pm$ 0.952 ($\pm$ 17° B.).

(Coalinga Field. Data by Thomas Cox.)

Initial Cost and Cost of Installation.

	Per cent.
Steam engines:	
A. Individual steam plant for each two wells, using oil for fuel	100
Gas engines:	
B. Individual 30-h.p. gas engines 4-cycle type, magneto ignition; including gas mains and accessories	195
Electric motors:	
C. Motor at each well, necessary transmission lines, transformers, and receiving station; power purchased	100
D. Central plant with steam turbines, fired with fuel oil, motor at each well	196
E. Central plant with steam turbines, fired with natural gas, motor at each well	227
F. Central plant. Engine-type generators, driven directly by gas engine. Electric motor at each well	264

Air compressors:

G. Central plant. Air compressors directly connected to gas engines, using natural gas. Air distributed to each well for operating steam engines	388
H. Central plant. Steam-driven air compressors, boilers fired by natural gas. Air distributed to each well for operating steam engines	393
I. Central plant. Steam-driven air compressors, boilers fired with fuel oil. No gas lines. Air distributed to each well for operating steam engines	337

Cost of Operation and Maintenance.

Steam engines:	Per cent
Comparative working cost of operation equipment A	100
Cost of operating steam plants, based on 100-month wells, per well per month, one pumper per well:	
Labor attendance	$104.88
Fuel oil	105.47
Labor, scaling boilers	15.62
Repairs, material	9.57
Engine repairs	5.56
Lubricating oils	7.73
Boiler flues	4.00
Water	17.17
Per well per month	$270.00
Per well per day	$9.00

Gas engines:	
Comparative working cost of operating equipment B	34
Pumping cost for 8 wells with two men in attendance per month:	
Labor, 2 men, at $3.50 per day	$210
Lubricating oils, $7.50 per well	60
One-quarter of 2 repairmen, at $8.50 a day	66
Repairs and renewals	120
8 wells, per month	$456
Per well per month	57
Per well per day	1.90

Electric motors:	
Comparative working cost of operation:	
Equipment C	80
Equipment D	61
Equipment E	50
Equipment F	44

Air compressors:	
Comparative working cost of operation:	
Equipment G	46
Equipment H	56
Equipment I	73

Remarks. Percentage costs are based on investment for equipment necessary to operate 50 wells, pumping 100 bbls. a day per well. Steam plants using fuel oil, and placed between each of two wells, with 2-pump attendants to each two wells, are considered as unity for basis of comparison.

The Thermal Efficiency of Gas Engines of the Size and Character Available for Use of the Oil Field averages between 20 to 30%, such engines require from 8.5 to 13 cu. ft. of natural gas per h.p.-hr. At certain wells 2,700 ft. deep with 30 h.p. four-cycle

type engines the hourly consumption of natural gas is about 4,000 cu. ft. when pumping at about 160 r.p.m. With oil producer gas from 40 to 60 cu. ft. per h.p.-hr. are necessary and the yeld of gas per lb. of oil will usually range from 50 to 70 cu. ft.

Cost of Pumping by Electric Power. The actual expenditure of electric energy for pumping varies widely. The average used in 71 wells, each about 1,600 ft. deep, over a period of time for which records were kept, was 70.6 kw.-hrs. a day, which, at 1.5 ct. a kw.-hr., made the daily cost for pumping per well a trifle over $1.05. The deepest well, 2,692 ft., used about 90 kw.-hrs. daily.

In another instance the average for 2 months for 8 wells varying in depth from 1,000 to 2,800 ft. was 93 kw.-hrs. a day. In another instance the average for 12 wells averaging 1,100 ft. in depth, with oil of a specific gravity of 0.9622 (15.5 degs. B), was 71.5 kw.-hrs a day. The average for another group of 107 wells, averaging 800 ft. in depth, with oil of a specific gravity of 0.9756 (13.5 degs. B.), was 57 kw.-hrs. a day. In another instance, with 58 wells pumped by three motor-driven jacks, the average per well a day was 26.2 kw.-hrs. For another group of some 220 wells operated by jacks, the cost of electric energy per well per month varied from $6 to $14.40.

Electric power in the field is sold at varying prices, the common figure being about 1.5 cts. per kw.-hr.

Cost of Pumping Water for Irrigation Purposes. The following data on pumping water have been taken from Water Supply Paper 222, U. S. Geological Survey. In the district about Bakersfield, Cal., 50 pumping plants are in use to develop irrigation water. Half of these are electrically operated and belong to the Kern County Land Co. Each of these plants is equipped with 30 or 40 h.p. motors direct connected with No. 8, 10 or 12 centrifugal pumps. Each pump is connected with from three to five 13-in. wells, the number being determined by the yield of each well. From the data collected on these wells, the following cost averages were computed, on the basis of the quoted charge of 15 cts. per h.p. per 24 hrs., for the electric power used:

Average depth to the water from the surface, ft....	10
Average suction 20 ft. Average total lift, ft.....	30
Total yield of 25 plants, in sec.-ft.................	100.34
Total h.p. consumed	860
Total cost per day to develop 100.34 sec.-ft., 860 h.p. at 15 cts.	$129.00
Cost per sec.-ft. for 24 hrs.	$1.29
Cost per acre-ft. of water developed	$0.65

The following data are for the cost of operation on a privately owned steam plant, which has a particularly advantageous location:

Equipment: 30 h.p. steam engine, No. 12 centrifugal pump, five 15-in. wells 40 ft. deep; 6 ft. to water, 15-ft. suction, 21 ft. total lift:

Cost of crude oil (fuel) and lubricant for 24 hrs.......	$2.25
Cost of labor 24 hrs.	4.00
Total cost	$6.25

Yield of plant in sec.-ft.	7
Cost per sec.-ft. for 24 hrs.	$0.89
Cost per acre-ft. of water developed	$0.45

Neither of these estimates makes any allowance for interest on investment in well and plant nor for deterioration, hence the costs as given are somewhat too low.

Cost and Efficiency of Various Units in Irrigation Pumping in California. Pumping for irrigation is of two principal classes: (1) pumping from wells to utilize underground waters; (2), pumping from streams or low level canals to canal systems at higher level. Government investigations into the possibilities of pumping for irrigation have been made largely with the first class of projects in mind. These studies, though somewhat scattered, are the best sources of information available to the general irrigator and are summarized in Engineering and Contracting, Aug. 30, and Nov. 22, 1911.

California Tests of 1905. These tests were made by the Office of Experiment Stations, Department of Agriculture, in the summer of 1905, and comprised 38 complete tests.

For the gasoline engine and steam engine driven plants the plant efficiency is the ratio of the useful water h.p. to the indicated h.p. For the electrically driven plants the plant efficiency is the ratio of the useful h.p. to the electrical h.p.

The final relation of fuel consumption to water lifted is expressed as the number of gals. of oil or the number of k.w.-hrs. required per useful water h.p.-hr. In reducing this to actual cost the price paid by the pump owner per gal. of gasoline per bbl. of crude oil or per kw.-hr. has been used. The number of hrs. which each plant runs per year, the cost of the plant and the cost of attendance and repairs have each been obtained as accurately as possible. From the nature of the case these items are somewhat uncertain. The rate of depreciation of pumping plants varies through an enormous range, being determined largely by the skill and care of the attendant. Many plants are not insured at all. Averaging all conditions found, the following appears to be a fair estimate of the rates suitable for use in computing the fixed charges of the various types of plants:

	Per cent
Gasoline Engine Plants:	
Depreciation	12 to 15
Interest	6
Taxes and insurance	1
Average total	20
Motor-Driven Plants:	
Depreciation	7 to 9
Interest	6
Taxes and insurance	1
Average total	15
Steam Plants of Ordinary Type:	
Depreciation	9 to 11

Interest	6
Taxes and insurance	1
Average total	17
Highest quality steam plants — average	12

In the case of the larger steam plants that percentage has been chosen for each individual case which seemed suitable to the special conditions of the plant. These percentages are applied to the first cost of the entire pumping station, including the cost of wells. The latter of course varies greatly with the depth of the wells.

The item of labor is also a difficult one to estimate. Some plants employ an engineer during the whole year, and others only during the pumping season Others have one man to look after several plants and many plants have no attention whatever.

Gasoline Plants. Nine tests were made of gasoline engines running centrifugal pumps. The discharge varies between 0.328 cu. ft. per sec., or 147 gals. per min., and 5.94 cu. ft. per sec., or 2,666 gals. per min. The lift varies from 11.3 ft. to 96.5 ft. The pumps for lifts exceeding 90 ft. are compound centrifugals, all others are single runner pumps. The useful water h.p. varies from 1.65 to 30.9. The indicated h.p. varies from 5.64 to 63.1. This covers a wide range and includes within its limits the majority of pumping plants in use for irrigation in California.

The plant efficiency varies irregularly. It depends somewhat upon the condition of the gasoline engine, but probably chiefly upon the arrangement and condition of the pump and piping. All turns and obstructions in the piping, any variation in speed of the pump from the speed most suitable to the discharge and lift, any great length of discharge pipe. all tend to reduce seriously the plant efficiency. To secure the best results the size and speed of both pump and engine and all the connections and piping should be carefully planned for the special conditions under which the plant is to operate. In general the results indicate that the plant efficiency should vary from about 30% for the smaller plants to about 50% for the largest plants. Any unusual low value means a continual loss to the owner of the plant during its operation, due either to its careless handling or to its faulty design and construction.

The amount of gasoline used per indicated h.p.-hr. varies rather regularly from 0.154 gal. for the smallest plant to 0.100 gal. for the largest. The amount of gasoline used per useful water h.p.-hr. depends upon both the plant efficiency and the amount consumed per indicated h.p.-hr. and hence is quite variable. The amount of gasoline required per useful h.p.-hr. varies from about 0.5 gal. for the smallest plant to 0.2 gal. for the largest plants.

The plant efficiency in deep well pumps in general may probably be expected to surpass the efficiency of centrifugal pumps.

The price of gasoline has been remarkably low (7½ cts. per gal.) in southern California, because of the fierce competition of oil producers and refiners in that region.

In other pumping localities 10 to 12 cts. a gal. is considered a low price for gasoline.

On account of the great cost of wells, the total cost of plant bears no direct relation to the capacity of the pumping plant.

In many cases the charge for attendance and repairs on gasoline engines is merely nominal, but when there is a charge for attendance it is of considerable importance in comparison with the cost of gasoline. In nearly all the tests reported above the annual fixed charges for interest, depreciation, and taxes, computed at 20% on the total first cost of the plant, far exceed the cost of gasoline, attendance, and repairs per year. This relation evidently depends upon the number of hours the pump runs per year. Since in many cases the pumps are used to supplement natural stream flow, the amount of use of the pumps fluctuates from year to year. Hence the interest on the pumping plant is in the nature of insurance on the crop, and it is scarcely fair to charge this item in its entirety as cost of pumping.

Tables XLIVA, XLIVB and XLIVC give the results of the B tests. The costs per ft-acre-ft. are obtained from the corresponding items under the cost per useful water hp.-hr. by multiplying by 1⅛. The costs per acre-ft. are obtained from the preceding columns by multiplying in each case by the lift. These results are interesting as showing what it is actually costing irrigators in southern California to pump water.

Electrically Driven Pumps. The electrically operated pumps tested had approximately the same range in size as the pumps run by gasoline engines.

As a rule, the plant efficiency for the electrical pump is definitely higher than for a corresponding plant operated by gasoline. This is probably largely due to the fact that less energy is absorbed in the motor than in a gasoline engine. There is less variation in efficiency due to size of plant for an electrically operated plant than for a gasoline plant. The plant efficiency of electrically operated pumps should at least be as good as 40% for a pump of 5 useful water h.p. capacity, increasing to 55% for a pump with capacity of 40 useful water h.p.

As compared with centrifugal pumps, tests show the screw pump to be less efficient; the deep well pumps to have about an equal efficiency; the triplex and rotary pumps to have somewhat higher efficiencies, but no very conclusive statements can be based on so few tests.

Under the best conditions the smallest plants require about 1.6 k.ws. per useful water h.p. and the largest 1.4 k.ws. All these plants burn crude oil as fuel. The largest ones are very much larger than any of the gasoline or electric plants tested, and hence not strictly comparable with them.

For the plants using centrifugal pumps the plant efficiency does not seem to differ definitely from the efficiency for gasoline or electric plants. The plant efficiency of the plunger pumps is much higher than for any other type, while for the air lift plants it is very much lower.

TABLE XLIV-A. SUMMARY OF COMPLETE TESTS ON GASOLINE PUMPING PLANTS

Discharge per min, gals.	Lift, ft.	Useful water horsepower	Indicated horsepower	Gasoline consumed, total during test, gals.	Number of hours plant runs per year	Total gasoline used per year, gals.	Total cost of plant	Fixed charge per year at 20 per cent. on total cost of plant	Cost of gasoline per year	Cost of attendance and repairs per year	Total cost per year
147	44.4	1.65	5.64	0.97	300	261	$3,056	$611	$ 14	$50	$ 675
301	61.9	4.70	16.3	7.29	2,600	6,000	1,400	280	330	0	610
2,666	11.3	7.60	38.0	16.88	4,320	24,300	3,400	680	1,210	300	2,190
372	96.5	9.05	26.5	9.28	496	1,460	3,200	640	88	83	811
611	67.9	10.4	35.2	11.42	470	1,800	3,343	668	99	0	767
678	62.0	10.6	29.3	2.47	850	2,100	2,500	500	142	0	642
489	93.5	11.4	26.7	11.04	1,800	4,970	3,200	640	261	450	1,351
597	90.3	13.6	40.8	14.86	1,000	4,250	3,000	600	212	125	937
2,226	55.0	30.9	63.1	37.85	1,920	12,100	3,500	700	660	300	1,660
108	203.5	5.56	16.7	4.36	720	1,170	3,000	600	65	0	665
159	180.3	7.23	13.9	7.70	360	590	1,555	311	35	75	421

The average duration of the tests was 3 hrs. 12 mins. Average cost of gasoline $0.056 per gal. Av. cost per useful hp.-hr.: fixed charges, $0.179; gasoline, 0.020; attendance and repair, 0.018; total, $0.217. Av. cost per ft.-acre-ft.: gasoline, $0.027; total, $0.298. Av. cost per acre-ft. of water pumped; gasoline, $2.09; total, $21.71.

TABLE XLIV-B. SUMMARY OF COMPLETE TESTS ON ELECTRICALLY-DRIVEN PUMPING PLANTS

Discharge per min., gals.	Lift, feet	Useful water horsepower	Electrical horsepower	Kilowatts	Number of hours plant runs per year	Total kilowatt hours per year	Total cost of plant	Fixed charges per year at 15 per cent. on total of plant	Cost of electricity per year	Cost of attendance and repairs per year	Total cost per year
320	62.0	5.01	14.5	10.8	2,600	28,100	$1,150	$173	$ 657	0	$ 830
992	22.5	5.62	12.6	9.40	4,320	40,600	2,500	375	810	$350	1,535
566	60.3	8.57	22.0	16.48	1,440	23,600	1,600	240	590	223	1,053
1,333	28.1	9.45	55.2	41.2	2,880	118,700	3,000	450	2,130	500	3,080
620	94.3	14.7	31.9	23.8	....	......	....	...	....	...	....
494	122.4	15.3	31.6	23.6	558	13,200	3,400	510	330	132	972
817	188.9	39.0	71.2	53.1	3,000	160,000	6,000	900	4,100	1,200	6,100
221	38.2	2.13	7.16	5.34	1,100	5,870	1,500	225	117	0	342
194	63.0	3.08	8.42	6.28	2,160	13,600	3,580	540	340	150	1,030
337	63.0	5.36	13.1	9.76	2,160	21,100	4,950	740	530	150	1,420
310	75.0	5.87	11.1	8.29	1,440	11,900	3,000	450	214	100	764
333	88.8	7.46	13.7	10.29	....	......	....	...	....	...	....
305	98.1	7.55	15.4	11.50	1,400	16,000	2,000	300	322	0	622

Av. duration of tests, 2 hr.-6 min. Av. cost of electricity per kw.-hr., $0.022. Av cost per useful water hp.-hr.: fixed charges $0.041: electricity, $0.050; attendance and repairs, $0.011; total, $0.097. Av. cost per ft.-acre-ft.: electricity, $0.058; total, $0.133; Av. cost per acre-ft. of water pumped, electricity, $4.12; total, $9.12.

TABLE XLIV-C. SUMMARY OF COMPLETE TESTS ON STEAM-DRIVEN PUMPING PLANTS

Discharge, per min., gals.	Lift, ft.	Useful water horsepower	Indicated horsepower	Fuel oil consumed, total during test, gals.	Number of hours plant runs per year	Total fuel oil consumed per year, bbls.	Total cost of plant	Fixed charges per year	Cost of fuel oil per year	Cost of attendance and repairs per year	Total cost per year
259	164.0	10.7	31.8	122.8	....	....	.....	....	....	....	....
615	94.3	14.7	31.7	63.9	....	....	.....	....	....	....	....
768	213.4	41.3	107.8	185	4,320	3,460	$10,000	$1,600	$2,760	$1,650	$6,010
24,590	13.48	83.7	139	186.4	....	....	.....	....	....	....	....
23,350	13.39	78.9	134	109.5	....	....	.....	....	....	....	....
46,550	13.59	159.6	...	115.2	2,310	4,225	33,111	4,604	3,590	1,860	10,090
42,820	9.85	106.4	239	187.5	....	4,000	50,000	7,040	3,600	2,100	12,700
39,230	9.74	96.4	216	172.5	....						
1,750	247	109.2	117.0	....	....	....	.....	....	....	....	....
1,468	247	91.4	100.6	....	....	....	.....	....	....	....	....
.....	...	200.6	217.6	229	5,000	4,600	55,000	6,600	4,600	2,320	13,520
602	50	7.59	43.9	84	5,800	2,700	5,000	850	2,000	1,500	4,350
944	87.4	20.8	116.7	160	3,840	2,440	7,500	1,275	1,830	1,800	4,905
2,074	42	22.0	133.7	84.8	5,000	3,200	35,000	5,250	2,400	1,575	9,225

Av. duration of tests, 4 hr. 12 min. av. cost of fuel oil per bbl., $0.82; av. cost per useful water hp.-hr.: fixed charges, $0.019; fuel oil, $0.020; attendance and repairs, $0.013; total, $0.051. Av. cost per ft.-acre-ft: fuel oil, $0.028; total, $0.070. Av. cost per acre-ft. of water pumped, fuel oil $3.05; total, $4.86.

The amount of crude oil consumed varies from over 0.8 gal. per indicated h.p.-hr. for the smallest plant to a little over 0.2 gal. for the largest plants. For those using centrifugal pumps the amount of crude oil used per useful water h.p.-hr. varies from 2.5 gals. for the smallest plant to about 0.5 gal. for the most economical plants. A comparison with gasoline engines of corresponding size shows that at least four times as much crude oil is required when burned under a steam boiler as is needed of gasoline when used in an internal combustion engine. When steam plants run intermittently, considerable fuel is required in getting up steam preparatory to starting the plant, so it is probable that in such cases the actual performance of the plants required more fuel in proportion to the work done than is shown in the tests.

Conclusions. A comparison of the results obtained with centrifugal pumps using gasoline, electricity, and steam as motive power shows that, at the prevailing prices, to raise 1 acre-foot of water 1 ft. the cost of gasoline varies from 1½ to 5 cts., the cost of electricity varies from 4½ to 10 cts., and the cost of crude oil for generating steam varies from 1½ cts. upward. The total cost, according to the rates used for fixed charges and the figures obtained for attendance and maintenance, of raising 1 acre-foot of water 1 ft. for gasoline plants varies from 4 cts. upward, for electric plants it varies from 7 to 16 cts., and for steam plants it varies from 4 cts. upward.

In a direct comparison of the use of gasoline and electricity figures show the cost of gasoline to raise 1 acre-foot of water 1 ft. high to be 3.7 cts. and the cost of electricity to be 6.9 cts., while the total cost for the gasoline plant is 6.9 cts. and for the electric plant 8.8 cts. per foot-acre-foot.

In a direct comparison of the use of electricity and steam two tests were made in succession on the same plant under identical conditions. The results show the cost of electricity per foot-acre-foot of water pumped to be 5.2 cts. and the cost of crude oil for producing steam to be 3.6 cts.

In another test the pump was sucking air on account of a deficient supply of water. The results show that in this case having the pump too large for the water supply increases by about 10% the charge for electricity per acre-foot of water lifted.

Cost of Repairs on Well Pumping Plants. Few figures are available of the cost of maintaining well pumping plants for irrigation, and the following, though for the most part quite old, are therefore of interest. These costs were secured by the Government engineers in their studies of irrigation pumping in California:

Plant 1. This plant comprised a 30-h.p. induction motor operating an 8 × 24-in. deep well pump; pumping was done from a 12-in. well 300 ft. deep supplying 240 gals. per min. under 175-ft. head. The repair costs for this outfit for one year, 1905, were $257.70.

Plant 2. This plant comprised a 23-h.p. gasoline engine operating a 7 × 24-in. deep well pump; pumping was done from a

10-in. well 320 ft. deep supplying 143 gals. per min. under a 193-ft. lift. The repair costs for four years, 1902–5, were as follows:

Year	Cost of repairs
1902	$56.48
1903	82.75
1904	83.55
1905	34.19
Average cost for four years	$64.24

Plant 3. This plant comprised a 23-h.p. gasoline engine operating a No. 5 single centrifugal pump; pumping was done from a 10-in. well 385 ft. deep, supplying 458 gals. per min. under 58-ft. head. The cost of repairs for five years, 1900–4, were as follows:

Year	Cost of repairs
1900	$36.15
1901	13.50
1902	23.30
1903	54.78
1904	24.65

Cost of a Small Irrigation Pumping Plant. R. Sibley (Journal of Electricity, Power and Gas) gives the following cost of a small pumping plant supplying 1,600 gals. per min. near Acampo, Calif. The pumps were installed 12 ft. below the surface of the ground and connected to twin wells sunk 22 ft. between centers, the suction pipes from each well being joined at the center by a tee connection with the pump. When pumping the water stood at 7 ft. below the pumps in the morning, 14 ft. below the pump at noon and 16 ft. below the pump at night.

The contract accepted provided for 1 8-in. (Byron Jackson or Dow) centrifugal pump; 1 20-h.p. (Westinghouse or General Electric) motor complete with automatic starter, low voltage release switch, wiring, etc., complete, 1-Type H overload relay circuit breaker to be installed complete and ready for operation, including belting, check valve, suction 8-in., with 12-in. discharge, for the sum of $699.28; the owner to dig pit, bore well and lay foundation for motor.

The subdivided costs were as follows:

Equipment:

Pump and 25 h.p. motor as per bid	$ 699.28
1-35 ft. piece, 8 in. O. D. casing	26.95
2-9 ft. 5 in. pieces O. D. casing	16.94
2-8 in. flanged elbows	12.80
2-8 in. casing flanges	23.93
5-sets bolts and gaskets	3.55
1-8 in. tee	20.63
Extra labor	10.00
	$ 814.08

Concrete Work: This consisted of concreting the entire interior 4 in. thick, reinforced, with 5 pieces tapering from 12 in. to 0 in. No cost is made for the sand, as this was taken from the well-boring sand, being found

of excellent quality. The gravel was hauled 15 miles and no actual cost was made for the gravel itself.

Gravel:		
4 horses, 4 days at $1 per day	$	16.00
Labor: 1 man, 4 days at $2.25 per day		9.00
Cement: 61 sacks at 65c per sack		39.65
Cartage on cement — 2 horses and 1 man ½ day		3.25
Labor on setting concrete		21.00
Concrete forms 2 men 2½ days at $2.25 per day		13.00
Lumber for concrete forms and for pump house, 1,000 ft. at $25		25.00
	$	126.90
Pump House (lumber used from concrete forms):		
3,500 shingles at $2.50 per M	$	8.75
Sheeting		5.00
Labor on building		13.25
Nails		1.00
	$	28.00
Main Excavation:		
Pit 10 ft. deep, 10 ft. wide, 6 ft. to runaway	$	24.75
Cost of second pit and leveling off first pit		25.25
	$	50.00
Well Sinking:		
Boring two wells 12 in. diameter — 150 ft. and the other 350 ft. deep over surface of the ground	$	63.25
(Usual charge is for ½ pit depth, but in this case, charges were made for 40 and 43 ft., respectively).		
Cost of pumping quicksand encountered, 6½ days at $14 per day		91.00
Express charges		9.00
	$	163.25
Priming Pump:		
Priming pump	$	5.00
Iron ladder consisting of 9 pieces 2 ft. 6 in. x ¾ in.		1.50
	$	6.50
Total cost of plant		$1,888.73

Cost of Drainage Pumping in Louisiana. C. W. Okey (Engineering News, Oct. 14, 1915) gives the results of investigations of drainage pumping costs in Louisiana made by the U. S. Department of Agriculture. The results are given in Table XLIIIA.

Cost of Pumping Plant and of Pumping Water for Irrigation, Minidoka Project, U. S. Reclamation Service. The following costs from Engineering and Contracting, Jan. 24, 1912, were abstracted from a paper by Barry Dibble:

The Power House is a reinforced-concrete structure with steel roof trusses and purlins, covered by matched lumber and galvanized corrugated iron. It measures 149 ft. long by 50 ft. wide and 90 ft. high from the bottom of the tail-race to the peak of the roof. It contains five main generator units of the vertical type, each of 2,000-h.p. rated capacity, and operating under heads of 46 ft. from forebay to tail-race. There are also two 180-h.p. turbine-driven exciters. Each main unit consists of a single Francis

TABLE XLIII-A. EQUIPMENT DETAILS AND UNIT PRICES OF OPERATING EXPENSES, SO. LOUISIANA DRAINAGE PUMPING PLANTS

Plant and Location	Pumps: Number and Kind	Pumps: Capacity Size	Pumps: Capacity Total Sec. Ft.	Pumps: Capacity Depth, In per 24 Hr	Excess Lift (Actual Exceeds Effective), Ft	Power Transmission	Engines: Number and Kind	Engines: Size	Efficiency of Engine, Pump and Piping at Aver Effective Lift, Per Cent.	Boilers: Number and Kind	Boilers: Size	Fuel: Kind	Fuel: Unit Cost	Labor: Grade	Labor: Wages	General Plant Condition	Notes
Smithport, Lockport, La.	1 square wood-case centrifugal	32x12-in. impeller	..	...	2 0	Rope drive	1 slide-valve noncondens	11x12-in.	Not tested low	1 return-tubular	100 hp.	Coal and oil (a)	$4.00 per ton	Unskilled	$1.50 per day of operation	Poor	Large plant, on account of leaking levees
	1 do.	24x8-in. impeller	84	1.1	......	do.	1 do.	12x10-in.					$1 15 per 24 gal.	do.		do.	(a) Fuel changed from coal to oil in September, 1912
Willswood, Waggaman, La.	1 square wood-case centrifugal	42x16-in. impeller	..	....	6.0	Rope and bevel gear	1 slide valve noncondens	16x24-in.	12	2 water-tube	150 hp. each	Oil	$0 80 to $1.70 (b) per bbl.	Good	$3 00 per day of operation	Good	(b) In 1912, cost of fuel oil rose from $0.80 to $1.70 per bbl.
	1 rotary 1 horizontal cast-iron	7 ft. wide 36-in discharge	... 152	.... 1.4	5.0 2.0	Rope drive Direct-connected	do 1 double slide valve vertical	16x24-in. 14x14-in.	32	1 return-tubular	80 hp.	do.		Unskilled assistant	$1.50	do.	
Unit No. 1, Poydras, La.	1 horizontal cast-iron centrifugal	36-in. discharge	..	....	2.5 (c) 0 0 (d)	Direct-connected	1 slide valve noncondens	14x18-in.	28 to 45 (c)	2 return-tubular	80 hp.	do. Oil and coal	$0.00 per bbl	Engineer good	$1 80 per day of operation	New	(c) March, 1912, to August, 1913 (d) Since August, 1913
	1 do.	24-in. discharge	92	0.88	......	do.	do.	10x14-in.	32 to 55 (e)				$3.25 per ton	Fireman fair	$1.00 per day		(e) Increased efficiency due to changes in pumps and piping during 1913
Drainage District No. 1, Des Allemands, La.	2 horizontal cast-iron centrifugal	24-in discharge	75	0.05	0.3	Direct-connected	2 slide valve vertical	12x12-in.	65	2 return-tubular marine	60 hp. each	Oil	$1.15 per bbl.	Good	$1 50 per day of operation	Good	
Drainage District No 3, Raceland, La.	2 horizontal cast-iron centrifugal	30-in. discharge	120	1.25	0.75	Direct-connected	2 slide valve vertical	14x16-in.	35	2 return-tubular	100 hp.	Oil	$1 15 per bbl	Unskilled	$1.50 per day	Fair	
Unit No. 1, Gueydan, La.	2 horizontal cast-iron centrifugal	54-in. discharge	385	1.4	0.3	Direct-connected	2 Corliss non-condens	16x36-in	65	2 return-tubular	150 hp.	Oil	$0 80 to $1 25 per bbl.	Expert engineer, good fireman	$100 per mo. in 1912; $3 per day $1.50	New	About January, 1913, the engineer was changed from monthly wage to rate per day when operating the plant
Little Woods (Old Plant)	1 horizontal cast-iron centrifugal	48-in. discharge	100	0.32	2.0	Direct-connected	1 Corliss noncondens	16x36-in.	23 (f)	1 water-tube	150 hp.	Coal	$2 75 per ton	Expert engineer, good fireman	$90 per mo.	Good	(f) Test in 1909, change in pump and piping in 1911 probably much increased the efficiency
Little Woods (New Plant), Little Woods, La.	2 do.	48-in discharge	380	1.30	0 6	Herringbone gear	Electric motors	215 hp. each	60				(g)		$1.50 per day		(g) 1c per kw.-hr. plus $230 per month fixed charge
Jefferson Drainage District No. 3, Barataria, La.	2 horizontal cast-iron centrifugal	48-in. discharge	300	1.44	0 4	Direct-connected	2 Corliss noncondens	16x36-in.	65	2 return-tubular	150 hp. each	Oil	$1.15 per bbl.	Expert	$55 per mo.	New	

COSTS AND CONDITIONS OF OPERATION: SOUTHERN LOUISIANA DRAINAGE PUMPING PLANTS

Plant	Area, Acres	Year	Rainfall, In.	Run-off, In.	Aver. Effective Lift, Ft.	(a) Acre-Ft.-Ft.	Cost: Fuel	Cost: Labor	Cost: Repairs and Incidentals	Cost: Total	Cost: Per Acre	Cost: Per Acre-Ft.-Ft. (a) Total	Cost: Per Acre-Ft.-Ft. (a) Fuel	No. Days Plant Operated	No Times Boilers Fired Up	No of 24-Hr Days per Year at Full Capacity	Hr at Full Capacity per Fire-Up	Longest Period of Continuous Operation, Days	No. of times plant was run continuously more than following No. of days: 1	2	3	4	6	10	Notes
Smithport	647	1911(b)	57 52	33 35	5 2	9,400	$667	$351	$150	$1,168	$1 80	$0 125	$0 071	115	103	33	7 7	2	8	1	0	0	0	0	(a) Acre-feet of wa-
	617	1912(c)	52 23	40 80	5 5	12,190	705	342	170	1,307	2 02	108	066	108	77	49.5	12 0	4 3	12	5	3	1	0	0	ter lifted 1 ft.
	617	1913	60 01	37 77	5 8	11,840	780	215	35	1,030	1 60	087	066	86	68	34 2	12.0	3.8	10	3	1	0	0	0	(b) March, 1911, to
	647	1914*																							February, 1912, in-
	2,400	1909(d)	43 32	16 33	5 0	16,330	936	600	230	1,766	.73	.108	.057	45	30	20 0	7 3	2 5	3	1	0	0	0	0	clusive
	2,400	1910	43 08	11 58	5 0	11,580	616	500	180	1,296	54	.112	053	45	41	8 4	4 0	0 75	0	0	0	0	0	0	(c) March to De-
	2,600	1911	52 32	23 42	5.0	52,290	1,267	753	300	2,320	80	.092	050	69	61	10 2	7 6	3 50	5	1	1	0	0	0	cember, inclusive
	2,600	1912(e)	48 22	34 42	5 0	37,200	2,676	765	514	3,955	1 52	106	072	81	63	35 0	8 9	4	10	4	1	1	0	0	(d) June to Decem-
	2,600	1913	51 52	27 08	5 0	30,180	2,412	848	457	3,717	1.43	123	.080	68	60	17 5	7	2	6	2	0	0	0	0	ber, inclusive
	2,600	1914	42 25	15 05	5 0	16,320	1,210	426	404	2,100	.81	.129	074	41	30	0.7	6	2 2	2	4	0	0	0	0	(e) January to May
Unit No. 1,	2,500	1912(f)	70 52	28 28	2 1	12,420	1,098	640	244	1,982	.79	.160	088	114	77	41 8	10.5	14 0	12	0	7	4	1	1	and October to De-
Poydras	2,500	1913	63 15	38 82	4 5	36,580	2,314	1,261	347	3,922	1.57	.107	063	155	131	46 5	8.5	6 5	4	3	2	1	1	0	cember, inclusive
	2,500	1914	47 70	16 46	5 2	18,320	743	764	408	1,915	.77	.105	041	73	71	17 8	6 0	2 0	2	1	0	0	0	0	(f) March 9 to De-
Drain. Dist. No. 1,	1,880	1913	47 37	31 00	5 1	24,910	1,526	564	116	2,206	1 18	089	061	210	198	40 0	4.8	5 0	5	4	2	1	0	0	cember 31
Des Allemands	1,880	1914	45 70	25 83	5.3	21,340	871	517	65	1,453	77	068	.041	178	159	35.3	6.3	4 8	8	5	2	1	0	0	(g) March 17 to De-
Drain. Dist. No. 3,	2,250	1913	52 01	20 84	2 9	11,270	930	306	331	1,567	.70	.140	.082	90	90	15 5	4.1	0.75	0	0	0	0	0	0	cember 31
Raceland	2,250	1914	58 05	23 40	3.5	14,870	1,140	233	104	1,567	.70	.106	.077	78	71	18.7	6.3	1 60	3	0	0	0	0	0	(h) Area increased to
Unit No. 1, Gueydan	6,500	1912(g)	41 71	37 26	3 6	75,200	2,040	1,225	795	4,060	72	.062	035	196	185	40.0	4 1	4	0	3	2	1	0	0	7,500 acres in July
	(h)7,500	1913	77 01	65 86	5 0	104,000	6,013	1,321	631	7,965	1 06	.041	.031	No record	169	58.0	8.2	No record	No record						(j) October to De-
	7,500	1914	59 18	34 49	5.1	100,350	No record			5,175	60	.047	..	166	162	28 00	4.1	5 2	7	1	1	1	0	0	cember, inclusive
Little Woods	7,600	1908(j)	3 26	3.88	1 5	3,730	137	381	77	596	08	.160	.037	23	23	.	9 2	0 5	0	0	0	0	0	0	(k) Average for year
	7,500	1909	65 40	20 17	3 0	56,610	1,168	1,620	420	3,217	43	.058	.021	233	103	62.00	10 2	6 5	11	8	5	3	1	0	(m) January 1 to
	7,500	1910	51 25	7 94	4.9	24,380	652	1,303	295	2,250	30	092	.027	134	134	31 00	5.5	0 5	0	0	0	0	0	0	May 2; old plant
	7,500	1911	53 85	18 36	4 7	53,620	1,060	1,505	385	2,950	39	055	020	163	142	52 00	8 8	7.0	8	6	4	3	2	0	(n) Average for years
	7,500	1912	63 50	42 39	5.1	136,050	3,100	2,121	670	5,911	.79	043	.022	204	204	145 00	17 1	23.0	7	7	5	4	4	2	new plant
	(k)4,260	1913	46.04	24 28	5.0	62,300	1,375	1,565	1,000	3,940	92	063	022	182	180	00 00	8.0	2 0	2	1	0	0	0	0	(p) Electric power
	(m)2,400	1914	17 40	13.13	5.6	14,770	No record			2,120	.88	.143	.	59	58	30.00	5.8	1.2	1	0	0	0	0	0	(q) March 12 to De-
	(n)6,040	1914	50 60	20.46	4.5	46,760	3,032(p)	No record		5,030	..	.121	(p) .084	308	308	16.00	1.2	0.6	0	0	0	0	0	0	cember 31
Jefferson Drainage	(q)5,000	1913	49.60	28 42	5.1	59,070	2,585	692	480	3,737	.75	.062	.043	121	119	20.00	4.9	2 5	1	1	0	0	0	0	*No record
Dist. No. 3	5,000	1914	48 16	26 45	4 7	51,030	2,274	595	201	3,120	.63	.061	.044	104	97	18.3	4.5	2.9	5	1	0	0	0	0	

runner, 54 ins. in diameter, operating at 200 r.p.m., direct-connected to a 3-phase, 2,200-volt generator. The costs of the power house are given in Table XLVIII.

Transmission Line.—There are 38.4 miles of transmission line of 33,000-volt capacity. Copper transmission cable is strung on wood poles spaced 250 ft. apart, except at certain river crossings with spans from 700 ft. to 1,100 ft., where steel towers are employed. The costs of this transmission line is given in Table XLV.

Pumping Stations are three, the first located at the end of the gravity canal and lifting the water to the first level, the second about 1.75 miles distant, lifting a portion to the second level, and the third, another 0.75 mile distant, raising a final portion to the third level. The first station has a maximum capacity of 600 cu. ft. per second at normal speed. The lift at this station and at each of the others varies from 30 ft. to 31 ft.

TABLE XLV. COST OF TRANSMISSION LINE, MINIDOKA IRRIGATION PROJECT

	Power line cost Total	Power line cost Per mile of line	Pole line cost Total	Pole line cost Per mile of line
Surveys and location	$ 18	$ 36	$ 175	$ 17
Clearing 100-ft. right-of-way	....	....	356	34
Pole and tower line complete, except conductors:				
Material	1,035	2,070	2,129	203
Freight and hauling	255	510	1,333	127
Labor	803	1,606	1,685	161
Conductors (transmission and telephone):				
Material	610	1,220	2,655	253
Freight and hauling	83	167	557	53
Labor	75	150	670	64
Superintendence and clerical	18	36	200	19
Miscellaneous	40	80	397	38
Engineering	23	46	220	21
Total	$2,960	$5,920	$10,377	$990

The buildings are reinforced concrete, 140 ft. long, 18 and 30 ft. wide and 45 ft. high. The first station contains four 125 cu. ft., and one 75 cu. ft. pumps; the second contains four 125 cu. ft. pumps, and the second contains two 125 cu. ft. and one 75 cu. ft. pumps. The pumps are installed in separate compartments and are direct connected and operated by 600-h.p. synchronous motors located directly above them. The costs of the pumping stations are given in Table XLVI.

Costs of Operating. The costs of operating the pumping system are given in Table XLVII. Referring to this table a rate of depreciation of 5% per annum has been applied to the stations and 10% to the transmission lines. No interest is included, as the money for the work comes from the reclamation fund, which is prac-

TABLE XLVI. COST OF PUMPING STATIONS AND EQUIPMENT, MINIDOKA IRRIGATION PROJECT

	Number 1	Number 2	Number 3
Excavation	$ 2,100	$ 5,300	$ 2,000
Building	35,000	40,000	19,500
Hydraulic machinery	27,200	23,000	16,200
Electrical machinery	44,700	42,800	17,300
Freight and hauling	10,300	9,600	5,500
Erection	15,800	14,600	9,300
Camp and permanent quarters	4,000	11,000	500
Engineering and incidentals	5,000	3,000	2,000
Administration charges, etc.	8,500	7,000	5,500
Total	$152,600	$156,300	$77,800
Capacity — cubic feet per second	575	500	325
Cost per second-foot capacity	$265.40	$312.60	$239.40
Pressure pipes, including administration charges	$21,400	$16,500	$20,200
Total length of pressure pipes — feet	849	540	825
Cost per foot	$23.90	$30.30	$24.50
Cost per second-foot of capacity, including pressure pipes *	$303.00	$346.00	$301.00

* Average $318.00.

TABLE XLVII. COST OF OPERATING AND MAINTAINING PUMPING SYSTEM, MINIDOKA IRRIGATION PROJECT

	Power house	Transmission line	Pumping Stations No. 1	No. 2	No. 3	Total
Operation						
Labor	$ 5,700	$ 700	$ 2,100	$ 2,100	$2,100	.....
Supplies	950	100	200	200	150	.....
Repairs:						
Labor	900	600	600	600	400	.....
Supplies and material	300	100	100	100	80	.....
Superintendence, clerical, camp, etc.	1,700	200	700	700	500	.....
General expense and administration	450	50	150	150	100	.....
Total operating expense	$10,000	$1,750	$3,850	$3,850	$3,280	$22.730
Depreciation	21,700	3,400	7,600	7,800	3,900	44,400
Total	$31,700	$5,150	$11,450	$11,650	$7,180	$67,130
Annual cost per acre, including depreciation	$0.660	$0.108	$0.239	$0.243	$0.150	$1.40
Operating expense per acre (48,000 acres)	$0.208	$0.037	$0.081	$0.081	$0.068	$0.475

tically loaned to the settlers without interest. In the table allowances for repairs, etc., has been increased over that so far needed, as this item will undoubtedly increase with time. It is not intended to include the item of depreciation in the annual charge made against the settlers. However, this item will have to be met as time goes on and the machinery wears out. This can be done by paying for replacements as they are needed, and in the meantime the settlers will have the use of their money, which

is worth 10 to 12% interest, whereas if the government collected a depreciation fund it would have to hold it without interest.

During the season of 1911, 114,000 acre-feet of water were pumped to the average height of 66 ft., equivalent to 7,560,000 acre-feet lifted through 1 ft. The operating cost for this pumping was about $0.003 per acre-foot lifted through 1 ft., and the depreciation amounted to $0.006. Next year more water will be pumped at practically the same total cost, and therefore the unit cost will be reduced.

Summary of Installation Costs:

Power house and accessories	$433,300	
Transmission line	34,000	
Pumping stations with pressure pipes	444,800	
Total investment on power system	$912,100	
Investment per acre (48,000 acres)		$19.00

Summary of Annual Charges:

Operation	$ 22,730	
Depreciation	44,400	
Total	$ 67,130	
Per acre (48,000 acres)		$1.40

A total of 14,000,000 kw.-hrs. was delivered to the pumping stations during the year at a cost of $37,000, including depreciation, or $0.0026 per kw.-hr. If, as would be necessary in the case of a commercial company, interest, taxes, etc., amounting to, say, 10% on the investment in the power house and transmission line, were added, the cost would have been $0.006 per kw.-hr.

TABLE XLVIII. COST OF 7,100-K.W. POWER HOUSE FOR PUMPING PLANTS, MINIDOKA IRRIGATION PROJECT

	Total cost	Per kilowatt
Building	$ 82,000	$11.70
Hydraulic machinery	73,000	10.40
Electric machinery	83,000	11.80
Freight and hauling	26,200	3.75
Erection	55,500	7.90
Tailrace	60,000	8.50
Roads and telephone lines	7,300	1.40
Camp and permanent quarters	23,200	3.30
Engineering and incidentals	11,100	1.55
Administration charges, etc.	15,000	2.10
Total	$433,300	$62.40

Rule for Converting Volumes of Water. In pumping costs, relative to irrigation, it should be remembered that an acre-foot amounts to 43,560 cu. ft. or very nearly 326,000 gals. (325,830); to change acre-foot to millions of gallons multiply by 3.07.

Thus when the cost per acre-foot lifted 1 ft. is $0.003, the cost per million gals. lifted 1 ft. is $0.00921.

Cost of Mine Pumping. R. V. Norris in the Transactions of the

American Institute of Mining Engineers, 1904, gives the following information on the cost of pumping at the Short Mountain Mine of the Lykens Valley Coal Co.:

A strike, which confined the work at these mines almost exclusively to pumping, gave an opportunity to determine with considerable accuracy the cost. The mines are deep, the present workings are 711 ft. below the sea-level, and about 1,600 ft. below the lowest surface-opening.

The pumping plant is divided into four lifts, shown in Table XLIX, which gives also all the other pump data. The greater part of the water is caught at No. 3 level and pumped from there to the surface. The pumps on No. 4 level handle only about one-third of the total pumped to the surface. Except the bottom lift, the pumps are all simple and direct acting, and many of them are old.

The records of the actual water pumped (plunger displacement) were accurately kept by counters on each pump; the labor costs, and repair and supply costs were known. At the boiler plants the labor, repair and supply accounts and the total coal used for steam at the colliery are accurate. During June, July and August, 1902, practically all the steam generated at the colliery was used in pumping. During the time 7,692 tons of coal were used for firing, of which it is estimated that 232 tons were used in supplying steam for accommodation hoisting, ventilation and in condensation in unused steam lines, leaving 7,360 tons for generating steam for pumping. During these months 207,034,324 gals. were pumped from an average depth of 1,152 ft., making an average of 0.035 tons of coal per 1,000 gals. (0.277 tons per 1,000 cu. ft.). On this basis, correcting for average depth and for use of different proportions of cylinder and Babcock & Wilcox boilers, we find for the years 1901 and 1902 as follows:

	1901	1902
Total water pumped (plunger displacement), gals.	567,113,616	1,116,320,253
Average depth pumped, ft.	1,141	1,093
Total estimated coal used, tons	21,200	37,963
Coal per M. ft. lb. in water, lbs.	8.87	8.51
Coal per h.p.-hr. in water, lbs.	17.56	16.85

As the average evaporation of the plant, with the proportion of cylinder and water-tube boilers in use June, July and August, 1902, was 6.64 lbs. of water per lb. of fuel, the total steam made during these months was about 109,470,000 lbs.

The ft.-lbs. of work used in pumping were 1,987,529,500,000; the duty of the pumps was about 18,156,000 ft.-lbs. per 1.000 lbs. of steam made by the boilers, which should be increased by 15% for steam used in Argand blowers and condensation, giving as the approximate duty of the pumping plant 20,880,000 ft.-lbs. per 1,000 lbs. of dry steam.

Dividing the total cost of making steam between the colliery and the pump-plant in proportion to the coal used, namely, 51% in

TABLE XLIX. MINE PUMP SIZES AND LIFTS

Level	Pump		Size column, ins.	Vertical lift including suction, ft.	Capacity gals. per min.	
4	Jeanesville, Comp. Duplex....24 and 38 by 10 by 36 in.		10	673	857	1,714
4	Jeanesville, Comp. Duplex....25½ and 38 by 10 by 36 in.		10	660	857	
3	Allison and Bannan Single...	27 by 12⅛ by 108 in.	8	321	691	3671
3	Allison single	27 by 12⅝ by 72 in.	10	321	737	
3	Allison single	38 by 16 by 72 in.	12	326	1,086	
3	Allison single	30 by 14¼ by 72 in.	10	326	1,156	
2	Allison single	36 by 16¼ by 72 in.	12	331	1,131	3817
2	Allison and Bannan Single...	25 by 12¼ by 72 in.	8	331	658	
2	Allison and Bannan Single...	38 by 16¼ by 72 in.	12	328	1,131	
2	Allison and Bannan Single...	30 by 12⅝ by 72 in.	8	328	897	
1	Bull Pump	44 by 21½ by 116 in.	20	319	866	3,755
1	Griscom Duplex	22 by 9$\frac{3}{16}$ by 36 in.	10 and 12	318	1,032	
1	Garter & Allen	26 by 11$\frac{9}{16}$ by 72 in.	8	293	852	
1	Allison	38 by 16¼ by 72 in.	14	317	1,005	

1901 and 77% in 1902, the total cost of pumping was as shown in Table L.

The last results are based on the assumption that the steam used will vary directly as the lift, and the labor cost of pumping will not be affected by the slight change in average lift.

The author says that in his 17 years of practice he had not until this occasion been able to arrive at even an approximate cost for pumping of this character and extent.

TABLE L. COST OF MINE PUMPING (1901–2)

	1901	1902
Total cost of labor, supplies and repairs for generating steam	$22,059.72	$19,728.28
Per cent. used for pumping	51	77
Cost of labor, supplies and repairs in generating steam for pumping only	$11,250.46	$15,190.78
Coal used, 21,200 tons at 50 cts. per ton	10,600.00	....
Coal used, 37,963 tons at 50 cts. per ton	....	18,981.50
Total cost of steam for pumping	$21,850.46	$34,172.28
Cost of labor, supplies and repairs for pumping-plant	8,915.06	12,236.09
Total cost of pumping	$30,765.52	$46,408.37
Total cost per 1,000 gals.	$0.0543	$0.0416
Average vertical lift, ft.	1141	1093
Cost per 1,000 gals., 1,000 ft. vertical height	$0.0495	$0.039
Cost per 1,000 cu. ft. 1,000 ft. vert.	0.3712	0.292
Cost per 1,000,000 ft.-lbs. in water	0.0060	0.0047
Cost per h.p.-hr. in water	0.0112	0.0093
Cost per h.p.-year, 24 hrs. per day, in water pumped	$98.11	$81.47
Cost steam only per year per boiler h.p. 24 hrs. per day	$17.77	$16.30

Costs of Irrigation Pumping. A. Potter (Engineering and Contracting, Jan. 27, 1915) gives the following comparative statement of fuel consumption of the various economical types of pumping engines investigated for an irrigation project near Eagle Pass, Texas.

The capacity of the plant was 67 cu. ft. per sec.; the lift, 37 ft.

Type of installation.	Fuel	Fuel consumption, 24 hours	Fuel cost per acre ft. (lift 37 ft.)
Humphrey gas pump	Wood.	8.83 cords	$0.100
Humphrey gas pump	Bitum. coal.	4.80 tons	0.145
Centrifugal pump and Diesel engine	Fuel oil	14.00 bbls.	0.211
Centrifugal pump and gas engine operated on producer gas	Wood.	11.35 cords	0.128
Centrifugal pump and gas engine operated on producer gas	Bitum. coal.	6.13 tons	0.185

The table is based on the following assumptions:

Thermal efficiency of Humphrey pump (over-all pumping h.p.), 20%.

Thermal efficiency of gas engine (brake h.p.), 24% + pump = 16%.

Thermal efficiency of Diesel engine (brake h.p.), 32% + pump = 21%.

Thermal efficiency of producer, lignite fuel, 75%.

Thermal efficiency of producer, wood fuel, 65%.

Mechanical efficiency of centrifugal pump, 65%.

Eagle Pass bitum. coal, $4.00 per ton, 12,000 B.t.u. per lb.

Mesquite wood, $1.50 per cord of 2,500 lbs., 6,000 B.t.u. per lb.

Fuel oil, $2.00 per bbl. of 335 lbs., 18,000 B.t.u. per lb.

The estimated cost of constructing the pumping station, including head works, forebay, diversion dam and surge tank, is $60,000, of which amount the machinery, including the producer, represents approximately 50%. The annual cost of maintaining and operating this pumping station, including fixed charges and depreciation, is $13,606. This amount is based upon irrigating the entire tract of 6,700 acres to a depth of 3 ft., corresponding to a fuel cost of 30 cts. per acre irrigated and a gross charge of $2.06 for all fixed charges and maintenance, including fuel.

The gravity project, on the other hand, involves an immediate expenditure of $300,000 and a yearly expenditure for fixed charges, maintenance and operation of $40,000. As the gravity canal would irrigate some 12,000 acres, this would place the gross charge per acre at $3.33.

The pumping project will show up still better than the gravity project during the development period. For instance, assuming one-quarter of the land in each project to be under irrigation, the gross charge under the pumping project would be $6.79 per acre, and under the gravity project, $13.35 per acre. This would be decreased to $4.62 and $6.68, respectively, when one-half of the land in each project is under irrigation.

Table LI gives a summary of results of 30 pump tests made on five Humphrey pumps at Chingford.

TABLE LI. RESULTS OF HUMPHREY PUMP TESTS

Pump No.	1	2	3	4	5
No. of tests	6	6	6	6	6
Average duration of tests, mins.	9.27	8.95	8.37	9.67	10.0
Lift, in feet	30.01	30.24	30.06	32.6	30.24
Water pumped, gals. per min.	40,088	39,327	39,656	39,196	21,739
Water horsepower developed	303.9	300.4	301.1	322.7	166.0
Gas used per min. at 60 degs. F. and 30 ins. mercury, cu. ft.	395.4	393.3	391.5	400.1	191.6
Calorific (lower) value of gas, B.t.u. cu. ft.	145.7	146.4	146.2	142.2	138.1
Average thermal efficiency, per cent.	22.39	22.19	22.33	24.07	26.63
Anthracite used per water hp.-hr., lbs.	.946	.957	.949	.881	.796

Formula for the Most Economic Size of Pipe to Carry Pumped Water. The following formula was deduced by Halbert P. Gillette in Engineering and Contracting, Jan. 25, 1911.

We propose showing that the most economic diameter for a cast iron pipe to carry pumped water is secured when the diameter in inches is equal to 15.7 times the square root of the number of millions of gallons of water pumped per day at eight hours. This simple rule, or formula, will be shown to be closely applicable even under wide variations of pipe, fuel and pump costs, etc. That such can be the case may seem incredible.

However, we shall show that in the general formula for most economic size of pipe (eq. 23), all the elements of cost occur under a radical sign and that their sixth root must be taken. When the sixth root of a factor is extracted, it is clear that the factor may have a wide range of variation without altering its sixth root very materially.

We think it will be difficult to find a better illustration of simplicity of a final formula in a problem of engineering economics where many factors enter than is seen in the one above announced, to the deduction of which we now pass.

While the numerical examples that we shall give will relate to cast iron pipe, the general formula (eq. 23) applies to any sort of pipe — wood, steel, etc.

It will be seen that, in solving for the most economic diameter of pipe, we use the method of the differential calculus. In other words, we solve for a minimum unit cost by first deriving a formula for the cost curve and then placing the differential coefficient equal to zero, which is tantamount to finding the point of the lowest point of the cost curve — the point where the tangent to the curve is horizontal. Engineers who do not understand the calculus can arrive at precisely the same results by substituting the values of the various factors in equation (18), and then substituting various values for the diameter of the pipe, x, until, by successive approximations, a minimum value for the total cost, I, is derived. However, that is a crude — though very common — method of solving problems in engineering economics. The differential calculus used in solving for minimum values is exceedingly simple, and it has the immense advantage of enabling us to derive general formulas, or rules, for quickly ascertaining the most economic combination in any given case. In brief, it enables us to deduce the general formulas of engineering economics, such as the one above expressed, and more particularly such as that given by equation (23).

The symbols that will be used in this discussion are as follows, arranged alphabetically:

A = area of waterway of pipe in square feet.
B = number of British thermal units (B. t. u.) per pound of fuel.
C = tons (2,240 lbs.) of fuel used per year pumping.
E = thermal efficiency of pump, engine and boiler (being the product of their several efficiencies).
G = millions of gallons pumped in day of 8 hours.
g = acceleration of gravity, 32.2 ft. per sec.
h = actual head in feet,

H = friction head in feet.
J = capitalized cost of labor for operating pumping plant.
K = total capitalized cost of pipe line in dollars.
L = total length of pipe line in feet.
M = capitalized cost of fuel.
N = number of seconds of pumping per year.
n = number of hours of pumping.
p = price of fuel in dollars per ton.
P = capitalized cost of pumping plant.
Q = cubic feet of water pumped per second.
r = per cent. of interest on capital.
R = work of overcoming the resistance of friction of water in pipe, expressed in foot-pounds for each second.
s = capitalized cost per lineal foot of pipe line in place.
T = total capitalized cost of pipe line plus capitalized cost of pumping plant plus capitalized cost of fuel and labor.
t = the fraction of a dollar by which the diameter of the pipe (in inches) must be multiplied to give the capitalized cost per lineal foot of pipe line.
V = capitalized cost per horsepower of pump.
W = weight in pounds of water pumped per second.
X = inside diameter of pipe in feet.
x = inside diameter of pipe in inches.

The total capitalized cost of any plant is the sum of its first cost and its capitalized annual expenses of operation, maintenance and depreciation. To capitalize any annual expense, divide the annual expense by the rate per cent. paid for the use of capital. Where the total output of the plant is a fixed number of units of work or product per year, we may, therefore, regard the total capitalized cost of the plant as being the "unit cost."

To illustrate what we mean by capitalized cost of a structure or machine, let us assume that the first cost of a pumping plant is \$70, and that the annual cost of maintenance (including depreciation) is \$7. If the rate of interest on capital is 5 per cent., then the capitalized value of the \$7 is $\$7 \div 0.05 = \$140$. Adding this capitalized cost of maintenance, \$140, to the first cost, \$70, we have a total capitalized cost of \$210.

For a given annual output of product, that plant is most economic whose total capitalized cost is a minimum.

In the case under consideration — a pumping plant and pipe line — we may ignore the labor item of annual cost of operating the pumping plant, for it is practically a constant (within the limits of choice of sizes of pipe and of pumps needed to effect the greatest economy). A constant added to a variable disappears upon differentiating for a minimum value. To make this clear, however, we shall include the capitalized cost of labor of operating the pumping plant.

The grand total capitalized cost is

$$T = K + P + M + J \qquad (1)$$
$$K = Ls \qquad (2)$$
$$s = tx \qquad (3)$$
$$K = Ltx \qquad (4)$$

We shall discuss the numerical value of t below.

The total horsepower of the pump is

$W\ (h + H) \div 550$. Hence

$$P = \frac{V\ W\ (h + H)}{550} \quad \ldots\ldots (5)$$

$$W = 62.4\ Q \quad \ldots\ldots (6)$$

$$P \doteq \frac{62.4\ Q\ V\ (h + H)}{550} \quad \ldots\ldots (7)$$

$$x = \sqrt{\frac{fQ^3(4{,}032\ pn + 3{,}551\ rVBE)}{rBEt}} = 3.9$$

$$M \doteq \frac{p\ C}{r} \quad \ldots\ldots (8)$$

Substituting eqs. (4), (7) and (8) in eq. (1)

$$T = Ltx + \frac{62.4\ Q\ V\ (h + H)}{550} + \frac{p\ C}{r} + J \quad \ldots\ldots (9)$$

Any theoretical mechanics, wherein the subject of hydraulics is discussed, will give the same general formula for the friction head of water as is given in Weisbach, page 864, as follows:

$$H = \frac{f}{2g} \left(\frac{4}{\pi}\right)^2 \frac{L\ Q^2}{X^5} \quad \ldots\ldots (10)$$

$$X = \frac{x}{12} \quad \ldots\ldots (11)$$

Since $g = 32.3$, and $\pi = 3\ 1\text{-}17$, eq. (10) becomes

$$H = \frac{6259\ f\ L\ Q^2}{x^5} \quad \ldots\ldots (12)$$

The work done in moving the water against the friction head, H, is

$$R = W\ H \quad \ldots\ldots (13)$$

Substituting eqs. (6) and (12) in (13) we have

$$R = 62.4\ Q \frac{6259\ f\ L\ Q^2}{x^5} = \frac{390{,}562\ f\ L\ Q^3}{x^5} \quad \ldots\ldots (14)$$

The energy of the fuel used in overcoming this frictional resistance may be expressed in terms of the number of heat units (B.t.u.) in a pound of fuel, multiplied by 778 (the mechanical equivalent in foot pounds, of 1 B.t.u.), multiplied by the number of pounds of coal used per second. This product must be multiplied by the thermal efficiency of the pumping plant. Hence:

$$R = \frac{2{,}240\ C}{N} \times 778\ B\ E = \frac{1{,}742{,}720\ B\ E\ C}{N} \quad \ldots\ldots (15)$$

Hence:

$$C = \frac{N\,R}{1{,}742{,}720\,B\,E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Substituting in eq. (16) the value of R given in eq. (14), we have:

$$C = \frac{390{,}562\,f\,N\,L\,Q^3}{1{,}742{,}720\,B\,E\,x^5} = \frac{0.224\,f\,N\,L\,Q^3}{B\,E\,x^5} \quad \ldots\ldots\ldots\ldots (17)$$

Substituting eqs. (12) and (17) in eq. (9) we have:

$$T = Ltx + \frac{62.4\,QVH}{550} + \frac{62.4\,QV\,(6259\,fLQ^2)}{550x^5}$$
$$+ \frac{0.224\,pfNLQ^3}{rBEx^5} + f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

Equation (18) gives the grand total capitalized cost in terms of known constants and the pipe diameter, x. To solve for a minimum value of T, differentiate eq. (18) remembering that T and x are the only variables, and place the first differential coefficient equal to zero. This will give us the lowest point on the curve of capitalized cost. Note that the second and fifth terms on the right side of the equation are constants and disappear when we differentiate.

$$dT = Ltdx - \frac{5(390{,}562\,fVLQ^3)\,dx}{550x^6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$
$$- \frac{5(0.244\,p\,f\,N\,L\,Q^3)\,dx}{rBEx^6}$$

$$\frac{dT}{dx} = Lt - \frac{3551\,f\,V\,L\,Q^3}{x^6} - \frac{1.12\,p\,f\,N\,L\,Q^3}{rBEx^6} = 0 \quad \ldots. (20)$$

Solving for x we have

$$x = \sqrt[6]{\frac{fQ^3\,(1.12\,pN + 3{,}351\,rVBE)}{rBEt}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (21)$$

But

$$N = 3600n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

Hence:

$$\sqrt{\frac{fQ^3\,(1.13\,pn + rVBE)}{rBEt}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

Equation (23) gives, in the most general form, the most economic diameter of pipe (x), for it is this value of x that satisfies the condition of minimum capitalized cost in eq. (18).

Let us now consider the numerical values that should be assigned to the various constants in eq. (23), under any given conditions.

Values of Constants.— The coefficient of friction, f, is strictly speaking a variable; but it varies only in a slight degree within quite wide limits of pipe diameter (if we use Darcy's formula for the coefficient) or of velocity of water (if we use Weisbach's formula). On page 867 of Weisbach's Mechanics, we find:

$$f = 0.014 + \frac{0.017}{\sqrt{v}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

On the following page, Weisbach gives Darcy's formula for cast iron pipe, which is

$$f = 0.02 + \frac{0.02}{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (25)$$

x being the diameter of the pipe in inches.

In either case we can select a value for f that is practically constant within the limits of size of pipe or of velocity of water, under consideration. Nor shall we err materially in the value of x in eq. (23) if we call $f = 0.2$ for all sizes of pipe and velocities of water.

The price of coal per ton, p, may range from $2 to $5 without producing a great effect on the value of x in eq. (23), for the sixth root of $2 is 1.12, and the sixth root of $5 is 1.30. Assuming coal to cost $3 a ton, the sixth root of p is 1.20.

The number of hours actually pumped yearly may have a wide range, but generally a pump is worked only 8 or 10 hours daily for about 300 days in the year, so that $n = 2{,}400$ to 3,000 hrs. Even if it is worked 24 hrs. daily for 300 days or three times as long as the 8 hrs. that we shall assume, it will increase the value of x only 20 per cent., for the sixth root of 3 is 1.20.

The rate of interest on capital, r, is usually 4 to 6 per cent., and we shall assume $r = 0.05$.

The first cost per horse power of pumping plant will usually not vary far from $70. But to this must be added the capitalized cost of annual maintenance. If annual maintenance cost is 8 per cent. of the first cost, we have $5.60 per year per hp. for maintenance, which capitalized at 5 per cent. gives $112. Hence the total capitalized cost per horse power is $\$70 + \$112 = \$182$, which is the value of V in eq. (23).

The thermal efficiency of the pumping plant, E, is the product of the following efficiencies: (1) Thermal efficiency of the boiler, (2) thermal efficiency of the engine, (3) mechanical efficiency of the engine, and (4) mechanical efficiency of the pump. This product is usually about 0.05, or 5 per cent., for fairly large pumping plants, and rarely exceeds 7 per cent. We shall assume $E = 0.05$. Its value may be derived from known coal consumption per horse power of work done by the pumping plant in lifting water against the combined head and friction head. If, for example, the work thus done requires 4 lbs. of coal per hour per hp., and if the coal will yield 12,000 B.t.u. (British thermal units per pound), we have

48,000 B.t.u. required to do 1 hp. of work; but 1 B.t.u. = 778 ft. lbs., hence 48,000 × 778 ÷ 60 mins. = 622,400 ft. lbs. of coal energy to perform 33,000 ft. lbs. of pump work per minute. Dividing the 33,000 by the 622,400, we get about 0.05, or 5 per cent. thermal efficiency of the pumping plant.

The first cost of cast iron pipe, including trenching, laying, etc., is given quite closely by the following rule, applicable to all diameters from 4 ins. up to and including 30 ins., for heads of water up to 100 ft. *To ascertain the cost in cents per lineal foot of cast iron pipe in place, multiply the diameter in inches by* 14.

This rule is derived from actual detailed costs given in the Water Works section of the second edition of Gillette's Handbook of Cost Data. It applies very closely when cast iron pipe costs $30 a ton delivered on cars, and for ordinary rates of wages.

If there were no maintenance cost of the cast iron pipe, then the t in eq. (23) would be 0.14, according to the above rule. As a matter of fact, it is usually necessary to scrape cast iron pipe at intervals to remove rust, etc., from its interior, and it is certainly economy to do so wherever water is pumped through a pipe that has become even slightly tuberculated. We have no very reliable data as to the desired frequency of such scrapings, but we have accurate costs of each scraping (see Gillette's Cost Data, second edition, page 698 et seq.). Pipes that had accumulated scale for 14 to 20 years were scraped clean for 2 to 5 cts. per lin. ft. If we assume that a cast iron pipe is scraped once at 2 per cent. of its first cost, and if the scraping is done once in 4 years, we have 0.5 per cent. per year for cleaning. Capitalizing this at 5 per cent., we have 0.5 per cent. ÷ 5 per cent. = 10 per cent. Hence the capitalized annual cost of scraping is 10 per cent. of the first cost.

If cast iron pipe has a life of 40 years and if interest is 5 per cent., a sinking fund table shows that 0.8 per cent. of the first cost deposited annually in the sinking fund will amount to the full first cost at the end of the 40 years. Hence the capitalized cost of this depreciation is 0.8 per cent. ÷ 5 per cent. = 16 per cent. Therefore we have to add 10 per cent. for scraping and 16 per cent. for depreciation, or a total of 26 per cent., to the first cost of the pipe, to get its total capitalized cost. Hence if $t = 0.14$ for first cost, $t = 0.14 + (26 \text{ per cent.} \times 0.14) = 0.176$ (nearly) for the total capitalized cost. In other words, the total capitalized cost of the cast iron pipe in dollars per lineal foot is 0.176 times the diameter in inches.

The number of British thermal units per pound of coal, B, does not vary greatly from 12,000; hence we shall assume $B =$ 12,000.

Summarizing our various values for the constants in eq. (23) we have:

$f = 0.02$ (coef. of friction).
$p = 3$ (price of coal in dollars per ton).
$n = 2{,}400$ (hours pumped per year).
$r = 0.05$ (rate of interest).
$V = 112$ (capitalized cost of pumping plant, dollars per h.p.).

$B = 12,000$ (B.t.u. per lb. of coal).
$E = 0.05$ (thermal efficiency of pumping plant).
$t = 0.176$ (constant by which to multiply diameter of cast iron pipe in inches to get its capitalized cost in dollars per lin. ft.).

Substituting these values in eq. (23) we have:

$$x = 3.9\sqrt[6]{\frac{0.02\,Q^3\,(1.13 \times 3 \times 2,400 + 0.05 \times 112 \times 12,000 \times 0.05)}{0.05 \times 12,000 \times 0.05 \times 0.176}} \quad (24)$$

This reduces to

$$x = 7.3\sqrt{Q} \quad (25)$$

Thus, if 4 cu. ft. are pumped per second,

$$x = 7.3\sqrt{4} = 14.6 \text{ ins.}$$

If 4 cu. ft. are pumped per second for 8 hours, we have a delivery of 862,000 gals.

In order to convert eq. (25) into millions of gallons (G) pumped per day of 8 hours, we have:

$$x = 15.7\sqrt{G} \quad (26)$$

Hence if one million gallons are to be pumped in 8 hours, $G = 1$, and eq. (26) becomes $x = 15.7$ ins.

Expressing equation (26) in words we have this rule:

The most economic diameter (in inches) of cast iron pipe for carrying pumped water is found by multiplying 15.7 *by the square root of the number of million gallons pumped per day of eight hours.*

In using this rule, it should be remembered that we have assumed that the pump is working only 8 hours out of the 24, or that $n = 2,400$ in eq. (23). If n is three times as great, or $n = 7,200$, or pumping is done for 24 hrs. daily for 300 days in the year, then we must multiply the constant (15.7) in the above rule by 1.2, for the sixth root of 3 is 1.2. For a 24 hour day of pumping, the rule then becomes:

Multiply 18.8 *by the square root of the number of millions of gallons pumped per day of 24 hours, and the product is the most economic diameter of cast iron pipe in inches.*

Comparing Relative Economy of Pipes Made of Different Materials.— Equation (23) gives us a ready means of comparing the economic merits of different kinds of pipe through which water is to be pumped. Thus, if wood stave pipe is contemplated, plat the first cost per lineal foot of wood stave pipe of different diameters. On the curve of unit cost thus platted select a straight line that most closely fits the curve between the limits of size of pipe likely to be used. From this straight line derive the first cost value of t, as above indicated in the cast iron pipe example. Then estimate the life of the pipe, and derive the annual cost of depreciation, which must be capitalized and added to the first cost, as above explained. This will give the total capitalized cost value of t for

the wood pipe. Insert the proper coefficient of friction for wood pipe, bearing in mind that in eq. (10) the friction coefficient, f, is exactly four times the friction coefficient given by Kutter for use in the Chézy formula ($v = c\sqrt{RS}$). In other words, if Kutter's friction coefficients are available, multiply them by 4 to get the proper value of f to be used in eq. (23). Having selected the proper values of f and t for wood pipe, either substitute in eq. (23) and solve for x, or, more quickly, determine the ratio of $\frac{f}{t}$ for wood pipe to $\frac{f}{t}$ for cast iron pipe, and extract the sixth root of that ratio. This sixth root multiplied into the value of x in eqs. (25) or (26) will give the proper value of x for wood pipe. Thus the value of $\frac{f}{t}$ for cast iron is $\frac{0.02}{0.176} = 0.11$ nearly.

If the corresponding value of $\frac{f}{t}$ for wood pipe should prove to be 0.22, then the ratio would be $0.22 \div 0.11 = 2$. The sixth root of 2 is 1.12, hence eq. (25), for cast iron pipe, would become $x = 1.12 \times 7.3\sqrt{Q}$ for wood pipe. We assume this value of $\frac{f}{t} = 0.22$ for wood pipe merely for illustration.

Having determined the most economic diameter for both wood and cast iron pipe, the pipe to select is the one giving the lowest total capitalized cost (T) when the respective values of x are substituted in eq. (18), remembering that the second and fifth terms of the right hand member need not be considered, as they are constant, and that the length, L, need not be considered, as it is common to all terms containing the variable x.

However, if a numerical problem is worked out in this manner and the respective economic values of x for any two kinds of pipe be substituted in eq. (18), it will be seen that all terms except the first term in the right hand member of eq. (18) can be ignored in making the comparisons. In other words the element of added capitalized cost of pump or fuel is so slightly affected by differences in the pipe diameters of the two kinds of pipe under consideration that it may be ignored, the question then resolving itself merely into which kind of pipe shows the least capitalized cost per lineal foot.

CHAPTER XVIII

CONVEYORS, HOISTS, CRANES AND ELEVATORS

Belt, Flight, and Screw Conveyors. For handling loose material a troughed belt is required, and though the load that can be supported by a foot of belt is not great, the capacity of even a narrow belt is surprisingly high, owing to the speed at which a belt may be run.

The capacity of a belt conveyor, according to Reginald Trautschold in Engineering Magazine, August, 1916, that is properly suited to its load, is entirely a question of speed at which the belt is run, and obviously this should be the highest speed at which the particular material can be efficiently conveyed. Table I gives speeds for belt conveyors when handling various materials.

Fig. 1, shows the capacity of standard widths of belt conveyors when continuously and uniformly loaded and run at the economic speed for the material handled. This graphic presentation emphasizes the comparatively large capacity of belt conveyors. For instance, a belt conveyor only 12 ins. wide can handle nearly 90 tons of sand per hr., while one 36 ins. wide has a capacity of about 800 tons per hr. when run at a speed of 375 ft. per min. In practice it is customary to discount these capacities, as they are only attainable under perfect loading conditions. Ninety per cent. of the records should be attainable in a well designed and carefully operated system, however, and the subsequent discussion will be based on such attainment.

TABLE I. ECONOMIC SPEEDS OF BELT CONVEYORS FOR VARIOUS MATERIALS

Material	Average weight in lbs. per cu. ft.	Speed in feet per min.
Coke	33.5	250
Broken stone (coarse)	165	275
Lump coal	55	275
Ashes	45	300
Lime and cement	65	300
Ore (average)	125	350
Crushed stone	160	375
Sand and gravel	110	375
Fine coal	50	400

On Fig. 2 are plotted the power requirements of conveyors handling various materials at their economic speeds, the belts being continuously and efficiently loaded to capacity. The data

thus depicted apply to conveyors equipped with high grade lubricated idlers and should be slightly discounted for conveyors equipped with the corresponding grade of ball-bearing idlers. These more efficient idlers reduce the power requirements for horizontal travel of conveyor about 33⅓%. Though the data depicted by the curves and the results obtained from the formula are for fully loaded belts, i. e. belts carrying their maximum load as given on Fig. 1, they should also be used for belts handling 90% of their capacity, as the slight unavoidable variation in load leads to slightly increased power consumption.

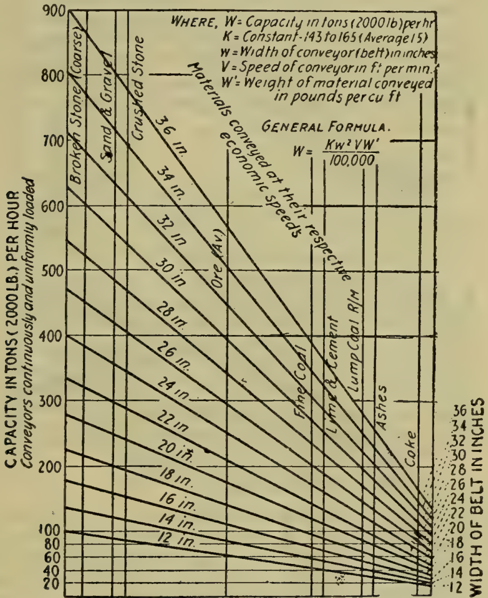


Fig. 1. Capacities of standard belt conveyors, economically loaded and operated.

The economy of belt conveyors in the consideration of power consumption is quite evident from a glance at Figs. 1 and 2. From the former it is seen that a 30-in. belt conveyor can handle about 270 tons of fine coal per hr. when operated at its economic speed for that material. Such a conveyor, elevating the coal 20 ft. and distributing it by means of an automatic traveling tripper over a storage bunker 50 ft. long, would require a supply of 13.5 h.p.— 5.5 h.p. for the horizontal travel, 5.5 for elevating the load, and about 2.5 for the tripper — if equipped with grease lubricated

idlers (see Fig. 2). Similar service by a conveyor with ball-bearing idlers would consume about 11.75 h.p.

In taking up the cost of belt conveyors, the questions of deterioration and amortization must be duly considered. In the handling of certain materials, lighter and cheaper belts — and the belt is the

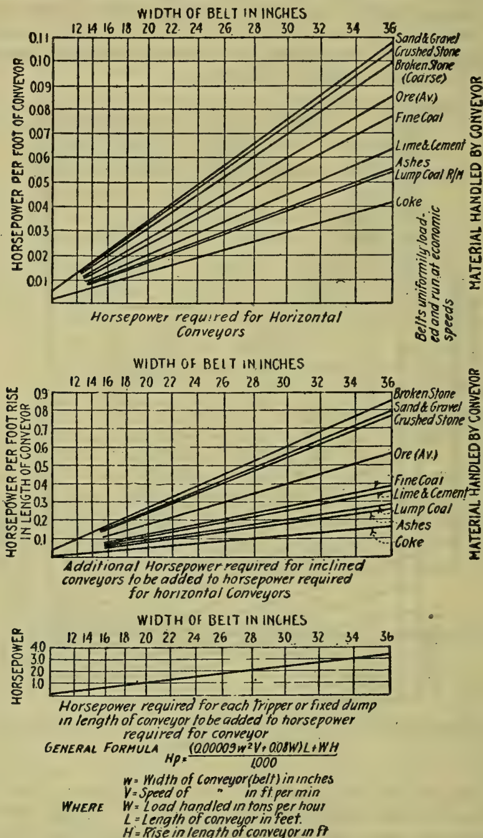


Fig. 2. Horsepower requirements of belt conveyors.

most expensive item entering into the equipment of a belt conveyor — may sometimes be recommended than that required for more severe service; but ordinarily the best grade of belt is none too good, no matter what service it may be subjected to. The

large capacity of the equipment makes the question of initial cost of secondary importance. The general formula given in Fig. 3 and the costs graphically depicted thereon are those for the average high grade belt conveyor with suitable rubber belting and well designed grease lubricated idlers. Cheaper conveyors may be purchased by sacrificing the quality of the belt, and more expensive ones by substituting idlers equipped with ball bearing. The cost of the belt is included in the first term of the second member of the formula, so that the cost of a conveyor with a cheaper belt is readily obtainable from the same formula simply by reducing the coefficient of the length by the difference in the cost of two ft. of high grade rubber belting and that of two ft. of the cheaper belt. Conveyors equipped with ball-bearing idlers, etc., cost about 5% more than the figures indicated by Fig. 3, but this difference in cost is frequently offset on shipments to distant points by the decrease in freight rates, ball-bearing idlers weighing less than grease or oil lubricated idlers.

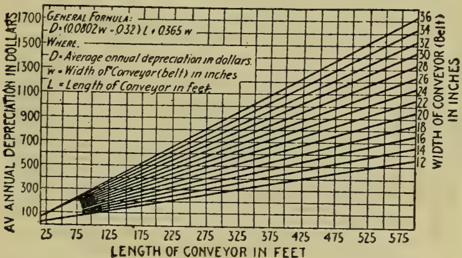


Fig. 3. Average cost of standard troughed rubber belt conveyors with grease lubrication.

Fig. 4 shows the average cost of the various discharging devices required for the belt conveyor. The prices indicated by the various curves and also those derived from the general formula are those commanded by high grade equipment. The values given on both Figs. 3 and 4 are conservative and may be taken as accurate during normal market conditions. More expensive equipment may prove economical, but cheaper equipment is not to be recommended.

The attention required, once a belt conveyor has been started up, is very slight, so that the labor charge for operating is extremely light, and in many plants could be overlooked entirely in an economic consideration. Belt conveyors do require periodic inspection and some attention if they are to be maintained in good operating condition, so they should rightfully be charged with some labor expense. An arbitrary charge which covers most simple installations of belt conveyors of ordinary length is about 1.5 cts. per hr. per in. width of conveyor for installations with grease

lubricated idlers, or a charge of 1 ct. per in. width for conveyors equipped with ball-bearing idlers.

The expense entailed for grease or oil and the other incidental supplies required to keep the equipment in good operating conditions is, in a conveyor in frequent use, very nearly directly proportional to the h.p. consumed in operating the conveyor, and

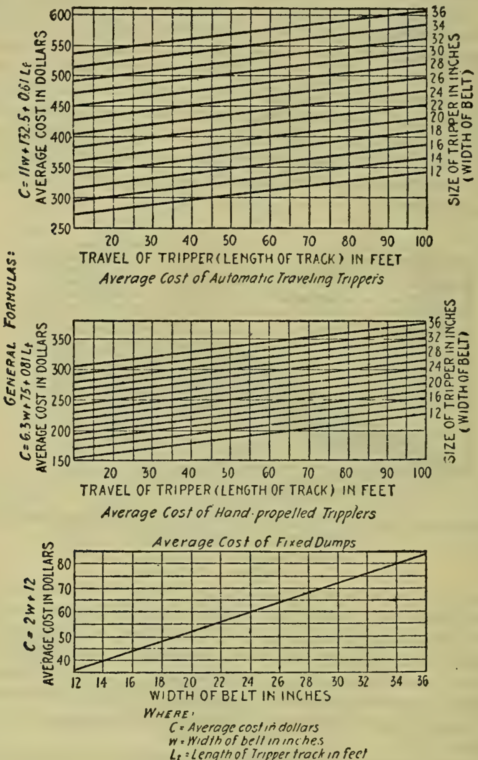


Fig. 4. Average cost of discharging devices for belt conveyors.

averages about 0.625 ct. per hr. per h.p. Of this charge about 0.5 ct. per hr. is the cost of the grease required, so that the average supplies charge for roller-bearing conveyors is but about 0.125 ct. per hr. per h.p. consumed.

Deterioration and amortization of belt conveyors constitute an exceedingly complicated subject and one that here must, perforce,

be treated in a very general manner. Depreciation is due not only to wear but to constant and quite apparent continuous deterioration of the belts, whether they are in use or not, so that the depreciation charge is little affected by careful use, provided, of course, that the equipment is operated a reasonable amount of the time. This deterioration is largely due to the hardening of the rubber cover and the loss of resiliency, and is more apt to be accentuated by idleness than by sane and careful use. The rest of the mechanism is not more greatly affected than other mechanical equipment, if well cared for and not abused. Ordinarily a depreciation charge of about 25% on the belt and about 10% on the balance of the equipment covers all reasonable wear and tear; the general formula on Fig. 5 is based on such apportionment. The curves shown are plotted from data compiled in a more intricate and exacting manner, but the discrepancy between the

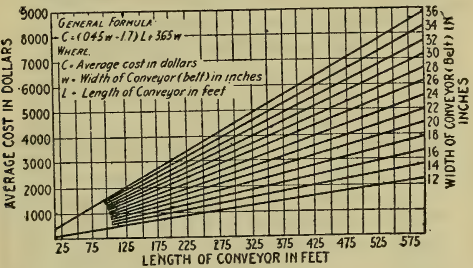


Fig. 5. Annual depreciation of standard belt conveyors.

results obtained from the general formula and the readings derived from the chart is so slight that dependence may be placed on either the figure readings or the formula. For conveyors with roller-bearing idlers the depreciation charge is reduced about 10%.

Belt conveyor installations are, of course, subject to the usual burden of fixed charges, consisting of interest on investment, insurance, and taxes. These ordinarily amount to about 8.5% of the initial cost per year (6% interest, 1% insurance and 2% of three quarters of the value of the property for taxes).

Flat belt conveyors for handling packages and other material which can be efficiently loaded on flat belts also prove highly economical in operation. The capacity of such belt conveyors depends upon the width of the belt and the speed at which they are run, as well as the proximity of the various pieces contributing the load. Their cost is usually somewhat less than that of troughed belt conveyors, and the power requirements are, of course, dependent upon the load handled. The general formula for troughed belts on the various figures, with the exception of the one on depreciation, are, as a rule, applicable to flat belt conveyors for handling packages, etc., if, in the formula for cost of equipment, correction is made for the cheaper belt which may be safely em-

ployed. The rate of depreciation is usually only about 25% of that for troughed belts, so, with this further correction, the economic value of flat belt conveyors can be readily obtained by calculation from the data for standard troughed belt conveyors.

Flight Conveyors. When great quantities of material which is not liable to damage by direct contact with the propelling flights have to be handled at a rapid rate in a limited space, when the cost of power is not a governing condition and the initial investment is a serious consideration, flight conveyors are frequently resorted to. Their capacity is great, owing to the compact load

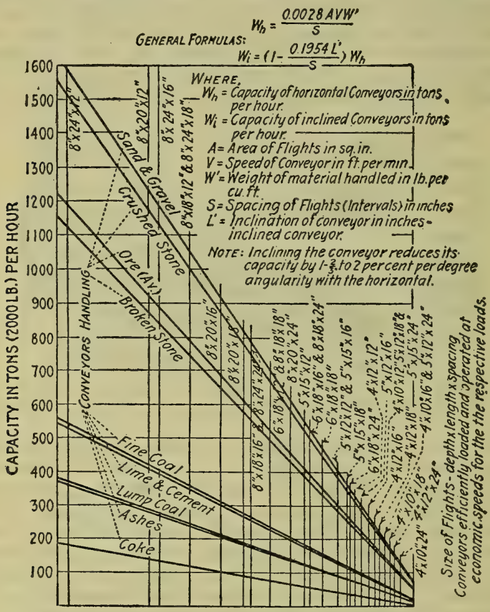


Fig. 6. Capacities of standard flight conveyors economically loaded and operated.

per foot, notwithstanding the comparatively low speeds at which they have to be run.

As in the case of belt conveyors, the economic speeds for various materials vary considerably, and the economic value of a flight conveyor depends upon its operation at the highest speed suitable for the load. Good practice is listed in Table II. These speeds are employed in figuring the capacities of various standard sizes of flight conveyors depicted on Fig. 6, and are to be recommended, although considerable variation is allowable in specific installations.

Fig. 6 is of particular interest in showing the great variety of

TABLE II. ECONOMIC SPEEDS FOR FLIGHT CONVEYORS FOR VARIOUS MATERIALS

Material	Advisable speed in ft. per min.
Coke	100
Broken stone (coarse)	125
Lump coal — run of mine	125
Ashes	150
Lime and cement	150
Ore (average)	175
Crushed stone	175
Sand and gravel	175
Fine coal	200

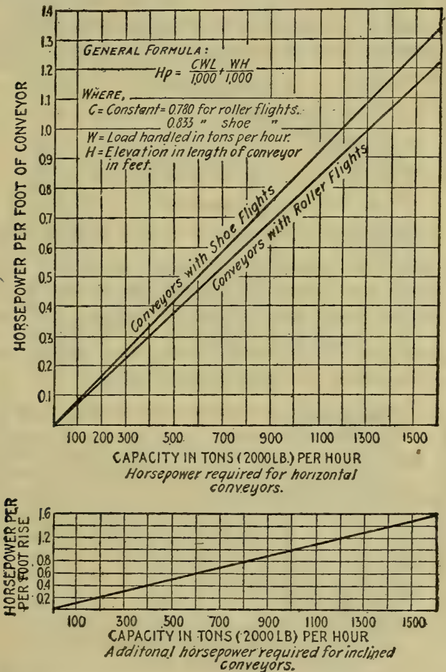


Fig. 7. Horsepower requirements of flight conveyors.

standard sizes of conveyors that are readily procurable. In many instances, there are several conveyors of different sizes and spacing of flights which have the same, or about the same, capacity at the same speed. These cannot be equally economical, so that even greater care should be exercised in the choice of equipment.

The selection is further complicated by the fact that the flights may be mounted on sliding wearing shoes or on rollers. The latter

construction adds to the cost of the conveyor, but reduces its power consumption. A general formula for calculating the power requirements of flight conveyors with double strands of chain, the usual type found in the manufacturing plant, and a graphic presentation of calculated results are given in Fig. 7. The reduction in power consumption carried by equipping the flights with rollers or wheels is not as great as is generally claimed, for the

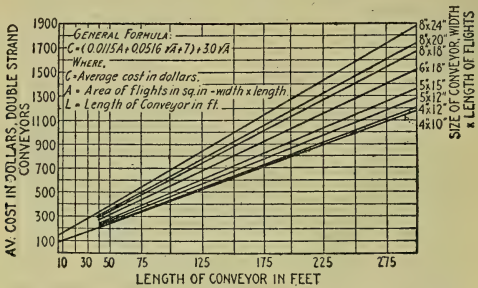


Fig. 8. Average cost of conveyors with sliding shoe flights.

main consumption of power in any flight conveyor is in dragging along the load, the power consumed in dragging forward the chains and flights being appreciably secondary. Sliding-shoe flight conveyors, when fully loaded, consume but about 10% more power than similar flight conveyors in which the flights are mounted on rollers. Equipping the flights with rollers adds to their cost

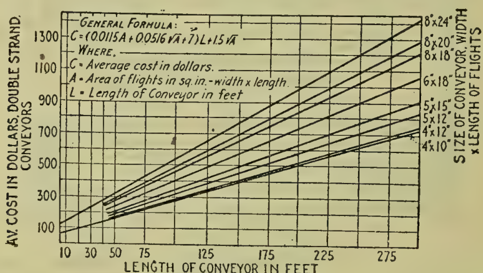


Fig. 9. Average cost of conveyors with roller flights.

to some extent, but reduces the rate of depreciation, and is in reality an economic gain.

The multiplicity of standards for flight conveyors and the differing spacing of flights make the derivation of an accurate formula for ascertaining the cost of the equipment an intricate and involved matter. Simple formulae which closely approximate average costs may be evolved, however, which serve for all practical purposes,

and such are given as the general formulae in Figs. 8 and 9. The data from which the graphic depiction of average costs on these figures are plotted are from averages of the estimated costs of a number of installations, which will be found to agree closely with results obtained from the respective formulae. It will be noted that in both the formulae and on the two figures no apparent consideration is given to the question of flight spacing, and that apparently the costs of conveyors of certain width and length of flights are the same, irrespective of the spacing of the flights. This is not quite true, but the variation in spacing of flights in standard flight conveyors of definite width is not sufficiently great to make any very appreciable difference in their cost — the expense entailed by a few additional flights constituting but a small proportion of the total cost of equipment, that is, in the average conveyor of reasonable length.

The depreciation of flight conveyors is naturally rapid, for the load exerts a very destructive scouring or abrasion on both the

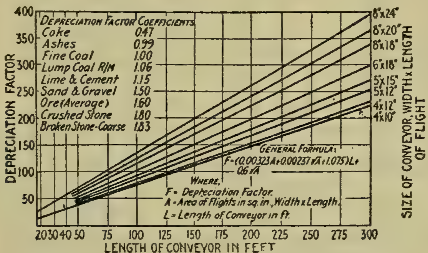


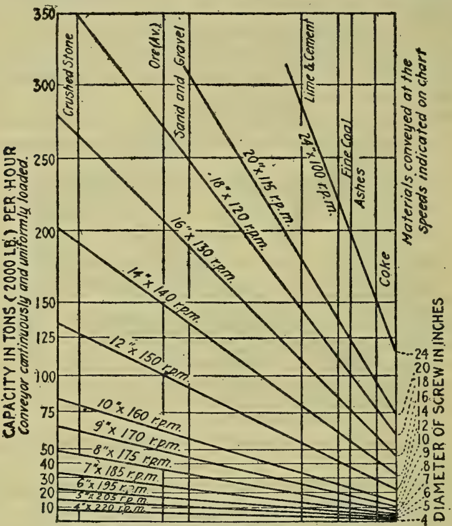
Fig. 10. Depreciation factors for standard flight conveyors.

flights and the trough. This deterioration is naturally much more pronounced when handling certain materials than it is when less destructive materials are dragged through the trough. The deterioration due to the handling of certain materials is so very much more marked, in fact, that the character of the load must be taken into consideration in any reliable investigation of the average depreciation charge. Arbitrarily assuming a convenient basis of comparison, an average depreciation factor is arrived at in the general formula on Fig. 10, which, when multiplied by the "depreciation factor coefficient" given on the same chart, gives the average annual depreciation in dollars. The depreciation amounts to about the same in similar conveyors whether they are equipped with sliding-shoe flights or with roller flights, although the rate of depreciation is slightly less for the more efficient type.

Flight conveyors are usually shorter than belt conveyors, and in addition they require more attention in the way of opening gates, etc., so that the labor charge per ft. of conveyor is higher than in the case of belt conveyors, and averages between 2 and 3 cts. per in. width of conveyor. It is not correspondingly higher per ton-

nage handled, however, because of the large capacity of a flight conveyor of the same width and length of flight.

The charge for incidental supplies, as in the case of belt conveyors, is almost directly proportional to the power requirements; and as a number of incidental repairs can logically be charged to the same expense, safe figures for this item are 2 cts. per hr. per h.p. for conveyors with sliding-shoe flights and about 10% less, or 1.8 cts. per hr. per h.p. consumed, for conveyors in which the flights are furnished with rollers. The incidental repairs on the latter type of conveyor, chargeable to the item of "supplies," are



GENERAL FORMULA:

$$W = \frac{0.3213 d^3 W' R}{100{,}000}$$

WHERE, W = Capacity in tons (2000 Lb.) per hour.
d = Diameter of screw in inches
W' = Weight of material handled in lb. per cu. ft.
R = Revolution of screws per minute.

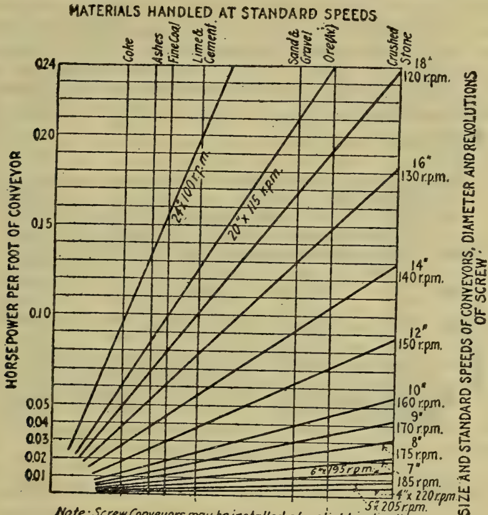
Fig. 11. Capacities of standard screw conveyors, economically loaded and operated.

less costly than those on flights with sliding shoes, but the lubrication charge is higher, so that the saving of the more efficient construction is only about 10%.

The burden of interest on investment, insurance, and taxes is proportionally no higher than in the case of other conveying equipment, and on the average amounts to about 8½% per year of the initial cost of the installation, in addition to which there is usually an annual renewal charge of about 20%, which is in excess of the depreciation usual to other conveyors.

Screw Conveyors. Notwithstanding its comparatively limited capacity and relatively high consumption of power, the screw conveyor possesses considerable economic value and finds many uses about certain manufacturing plants — particularly in cement mills.

Unlike the types of conveyors already analyzed, the economic speed of the screw conveyor is governed by its size (diameter of screw) rather than by the character of the material handled. Fig. 11 shows not only the capacity of the common sizes of screw conveyors handling the materials usually entrusted to them, but



Note: Screw Conveyors may be installed at a slight inclination with the horizontal in which case 0.001 horsepower additional is required per ton handled per hour for each foot rise in length of conveyor.

General Formula: $Hp. = \frac{0.68\,WL}{1{,}000} \times \frac{WH}{1{,}000}$

Where, W = *Load handled in tons per hour.*
L = *Length of conveyor in feet.*
H = *Elevation in length of conveyor in feet.*

Fig. 12. Horsepower requirements of screw conveyors.

also gives the advisable speeds at which to run the various sizes. These speeds may be varied to a considerable extent when conditions make such departure advisable, but a lower speed is apt to sacrifice efficiency, and higher speed is apt to lead to trouble.

In the consumption of power, screw conveyors are even less sparing than are flight conveyors, but as they are usually of comparatively short length — a series of screw conveyors discharging into one another being employed if they have to carry the load any appreciable distance — and have a quite limited capacity, their

relative extravagance in the use of power is no serious handicap.

Fig. 12 gives the horsepower required for standard sizes of screw conveyors per ft. when handling certain materials at their economic speeds. The general formula given for calculating horsepower requirements takes into consideration the elevation of load in inclined conveyors, but ordinarily screw conveyors are installed as nearly horizontal as possible; any inclination not only increases their consumption of power, but tends to reduce their capacity, unless some positive mechanical feeding device is installed.

Though there are many special types of screw conveyors on the market of differing design, the cost of the ordinary standard type follows a fairly well defined relationship, which is expressed by the general formula given on Fig. 13. The curves of the chart plotted from this formula forcibly indicate the low initial cost of this type of equipment — a few hundred dollars for any reasonable length and average capacity.

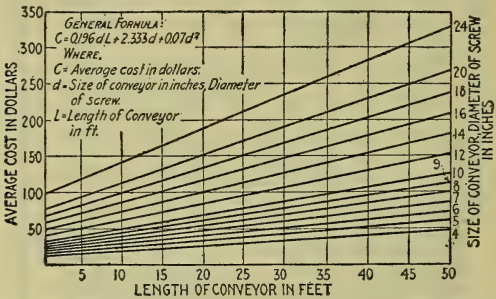


Fig. 13. Average cost of screw conveyors.

Though cheap in first cost, the depreciation of screw conveyors is more rapid than that of almost any other type of conveyor — the propelling screw revolving in the midst of the load is subjected to a very destructive abrasive action. As in the case of flight conveyors, different materials affect differently the life of the propelling mechanism and the trough carrying the load. For instance, cement and lime have a much more destructive action on screw conveyors than has coke. Based on a convenient unit of depreciation, coefficients are tabulated on Fig. 14, which, when multiplied by the depreciation factor obtained from the plotted curves, or calculated from the general formula given on the chart, give the average yearly depreciation of standard screw conveyors in dollars. This depreciation factor is based on the continual operation of the conveyor, so that in charging depreciation against a conveyor not in continual use only that proportion of deterioration which would be contracted in the actual working time should

be charged against the installation, provided, of course, the conveyor is in operation a reasonable number of hours per year.

Once the ordinary screw conveyor is started, it requires little attention, unless something goes wrong. The legitimate labor charge, therefore, is low. In order that there may be no interruption of service due to neglect, however, the conveyor should be frequently inspected, and if such inspection is charged to labor it will raise it to about 0.5 ct. per in. diameter of screw per hr., chargeable only during actual operating hrs.

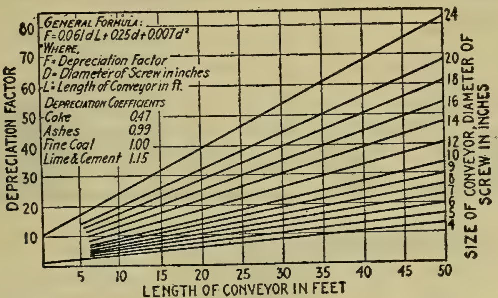


Fig. 14. Depreciation factors for standard screw conveyors.

The charge for individual supplies though averaging nearly directly proportionally to the power consumption of the conveyor, is much more serious than in almost any other type of conveyor; for unless the various bearings are kept well lubricated the material being conveyed works between the shaft and bearing and is very destructive. A charge of 1 ct. per hr. per h.p. is not an excessive amount for the supplies, and may be taken as a conservative average.

Cost of Belt Renewals and Power for Driving Belts. Edwin H. Messiter, in Engineering and Mining Journal, has stated that in good practice the life of belts will be such that the cost of belt renewals should amount to 0.1 ct. per ton of ore delivered to the belt, and the h.p. required for driving it will average 0.00015 h.p.-hr. per ton for each ft. of horizontal distance through which the material is carried, plus 0.001 h.p.-hr. per ft. of height elevated.

The Cost of Loading Bricks Into a Box Car Using a Portable Belt Conveyor. The following observations were made by A. C. Haskell (given in Engineering and Contracting, Sept. 15, 1915) at a large brick manufactory in New Jersey where common bricks were being loaded into a box car by means of a portable belt conveyor. The car was on a siding and the bricks were (a) in piles about 30 ft. away; and (b) brought in on small flat cars on an industrial track parallel to and 40 ft. from the siding.

The conveyor was mounted on two wheels of about 4 ft. diameter and was driven by a small motor supported on the frame work,

The belt was 20 ins. wide, 20 ft. long and had a speed of 240 ft. per min. The lower end was 1.5 ft. above the ground and the upper end 2 ft. above the car floor and extending about a ft. within the car.

One man (1) (Fig. 15) stood at the foot of the conveyor and received bricks, four at a time, passed to him by two others (2) and (3) alternately, from the piles. (1) placed them on the conveyor and (4) and (5), standing in the car at the door, one on either side of the belt, took them off and passed them to (6) and (7) and to (8) and (9) who piled them in the car.

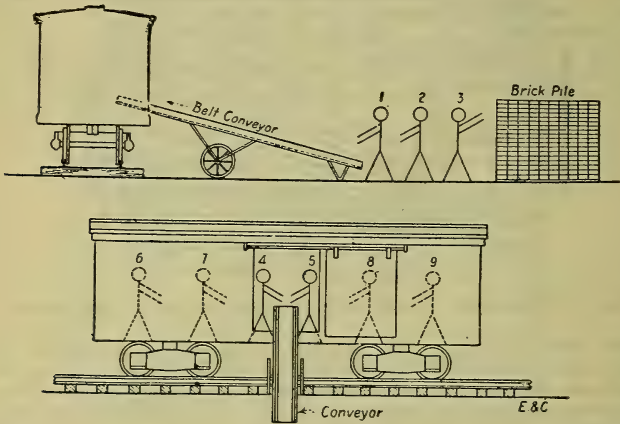


Fig. 15. Diagram showing positions of laborers loading bricks into a car with a belt conveyor.

From the flat Koppel cars which were run in as mentioned above, the bricks were loaded onto wheelbarrows, wheeled to the foot of the conveyor and stacked on four at a time.

The work was very fast and every unit was busy all the time. The only improvement that might have been suggested was that the bricks be placed with more uniformity on the conveyor. Sometimes they were put on in batches of four so close to one another that (4) and (5) could not get them off and they would pile up on the car floor. The foreman should have seen that the bricks were placed on the belt at equal intervals and with such frequency that the men in the car could just handle them.

The following time study was made when loading from the piles:

100	bricks were loaded in	1.07 mins.
102	bricks were loaded in	1.13 mins.
103	bricks were loaded in	1.17 mins.
100	bricks were loaded in	1.30 mins.
405	bricks were loaded in	4.67 mins.

On this basis in an 8-hr. day, $\frac{405 \times 480}{4.67} = 41{,}600$ bricks would be loaded, which is between three and four car loads. Allowing 45 mins. for shifting the conveyor, etc., the total would be reduced to 37,700.

9 men at $1.75	$15.75
1 foreman at $3.50	3.50
Conveyor at $0.50	0.50
	$19.75

or $19.75 + 37.7 = 52.4 cts. per thousand.

Therefore to load a car with 12,000 bricks, which is about the average, would cost $6.30. A time study was made when they were unloading bricks from the flat Koppel cars with wheelbarrows and transporting them to the conveyor.

The average number of men loading was two, and the average number of bricks loaded was 73 per min. The distance of travel to the foot of the conveyor was 30 ft.

Average speed loaded = 30/0.22 = 136 ft. per min.
Average speed empty = 30/0.13 = 230 ft. per min.

On the above basis the total number of bricks handled per day by the three wheelbarrows would be:

$$\frac{480}{2.57} \times 3 \times 73 = 40{,}900$$

Allowing, as before, for time to shift, the number would be 37,000:

2 men loading at $1.75	$ 3.50
3 men transporting at $1.75	5.25
9 men at conveyor at $1.75	15.75
1 foreman at $3.50	3.50
Conveyor at $0.50	0.50
	$28.50

Or at a cost of $28.50/37.00 = 72.2 cts. per thousand, or at the rate of $9.25 per carload.

TABLE III. COST OF ELEVATORS

	Buckets Size	Gauge	Weight, lbs.	Price
With geared head, 50 ft. centers....	13 × 10	No. 14	4,650	$490
With geared head, 50 ft. centers....	16 × 11	No. 14	5,835	585

"Back Gear Driving Connection" is an arrangement for driving the elevator and screen, particularly used with the smaller sizes, and takes power from the breaker.

The cost of the iron work for a countershaft is about $50.

Bucket Elevators and Conveyors. Reginald Trautschold in Industrial Management, Nov., 1916, states that for handling the

coal supply, etc., in a manufacturing plant, the bucket elevator is the most usually encountered equipment for elevating purposes. Such apparatus requires but limited space and delivers its load in a comparatively uniform stream, which develops good capacity and, at the same time, allows the discharge of the elevator to be handled easily and rapidly from the point of discharge, the buckets being of relatively small proportions and carrying small individual loads. Formerly the buckets were attached to the chains or belt contiguously in order to secure a continuous load, but this necessitated extremely low elevator speeds that the succeeding buckets might pick up suitable loads. Present practice is to space the buckets further apart and run the elevator somewhat faster, the buckets so arranged picking up more uniform loads and filling more satisfactorily. Bucket elevators with their buckets spaced some distance apart will therefore be the type analyzed in this discussion.

Table IV gives speeds at which various materials have been found to be most economically handled by standard bucket elevators, and these may safely be taken as representing the *economic speeds* of bucket elevators for the various materials.

TABLE IV. ECONOMIC SPEEDS FOR BUCKET ELEVATORS FOR VARIOUS MATERIALS

Material	Average weight in lbs. per cu. ft.	Advisable speed in ft. per min.
Coke	33.5	100
Broken stone (coarse)	165	125
Lump coal	55	125
Ashes	40–45	150
Lime and cement	65	150
Ore (average)	125	175
Crushed stone	160	175
Sand and gravel	110	175
Fine coal	50–60	200

The tabulated speeds suppose a certain interval between the buckets in order that each individual bucket may pick up a suitable load. Usually this means the spacing of the buckets from 12 to 18 ins. apart. Obviously the closer the buckets are arranged the greater the capacity of the elevator, provided that the individual buckets can pick up equal loads, so that the capacity of a bucket elevator is very nearly directly proportional to the spacing of its buckets, the speed being constant.

Fig. 16 depicts the capacity of standard sizes of bucket elevators when continuously and uniformly loaded and operated at the economic speed for the material handled. This chart illustrates the wide range of capacities of a comparatively few sizes of standard bucket elevators, and emphasizes the necessity of careful selection of equipment if the capacity required is accurately known. An elevator of excessive capacity usually means uneconomic operation — an idle piece of equipment being a costly investment — while an elevator of insufficient capacity is always an inexcusable economic blunder.

Bucket elevators being perfectly balanced when unloaded, the power required is simply that necessary for elevating the load, and for dragging the buckets through the charged elevator boot and overcoming the frictional resistance of the equipment; so that a simple formula can be derived for ascertaining the horsepower

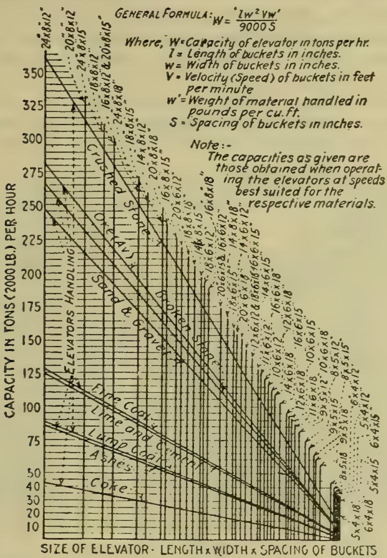


Fig. 16. Capacities of standard bucket elevators economically loaded and operated.

required for any particular installation. This formula might be expressed as:

$$\text{Hp.} = \frac{15\text{WH}}{10{,}000}$$

where

W = Load handled in tons per hr., as obtained from Fig. 16, and
H = Height to which load is elevated, in ft.

In the consumption of power, bucket elevators are not particularly economical, on account of the heavy frictional losses, the general inefficiency of the construction, and the resistance to the passage of the buckets through the charged elevator boot; but this drawback is compensated for in large part by the quite decided advantages of compactness of equipment, simplicity of construction, and uniformity of discharge. Furthermore, a bucket

elevator is a comparatively cheap piece of equipment and does its work well while in good condition, notwithstanding its rapid deterioration under severe usage.

Standardization of the cost of bucket elevator equipment is made difficult by the great variety of buckets which can be employed and the multiplicity of chains or belts which can be used for supporting the buckets. In general practice, however, the variations in design of elevator and in the type of equipment employed may be grouped into a few classes which permit conservatively accurate analysis of costs.

Three general designs of bucket elevators are in common use: First, elevators in which the buckets are attached to a single endless chain; second, elevators in which the buckets are attached to

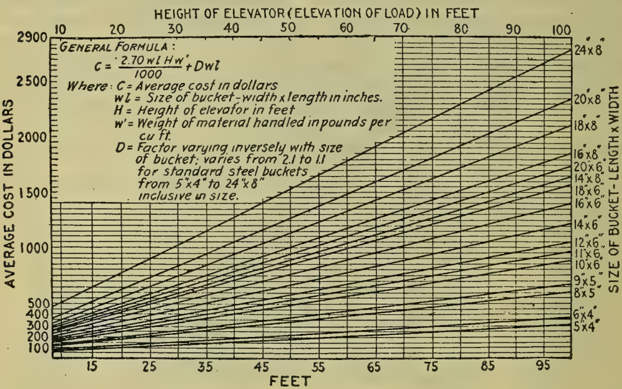


Fig. 17. Average cost of standard, double strand (steel bucket) bucket elevators. Standard detachable chain — buckets spaced 12 ins.

two matched strands of endless chain; and third, elevators in which the buckets are attached to an endless belt. Elevators employing but a single strand of chain are usually of small size and have to be installed at an inclination, in order that the buckets may satisfactorily discharge their load. These limitations naturally detract from the value and popularity of this type of design, and as the single chain has to be as strong as the combined strength of the two chains in double-strand elevators they are in reality little less costly than the more rugged and efficient double-strand elevator. Single-strand bucket elevators are also subject to more rapid depreciation, etc., so that they are no longer commonly found in the efficient manufacturing plant.

Double-strand bucket elevators can be run vertically by installing choke sprockets to divert the direction of the descending buckets, so that they may discharge their load without undue spill,

etc. This is the type of bucket elevator usually found in the manufacturing plant and the type to be recommended. Bucket elevators with buckets attached to an endless belt possess the same drawbucks as single-strand elevators, but also they possess the advantage of slightly lower initial cost, even when a high-grade rubber belt is employed.

Though the buckets which could be employed are numerous, the standard type of elevator bucket usually meets all requirements and may be of steel or of malleable iron. The more costly buckets are usually employed only for handling materials which are destructive to steel. The chains customarily employed for bucket elevators are either the ordinary detachable link chain, com-

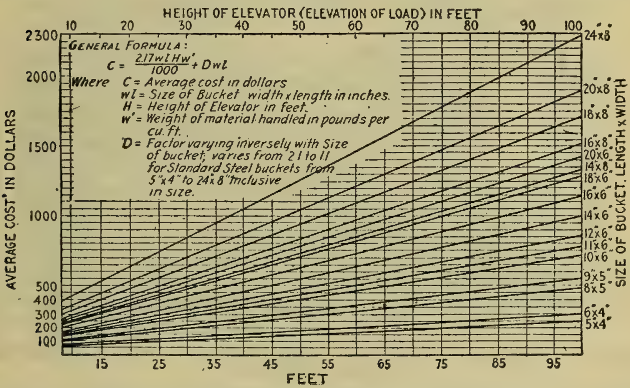


Fig. 18. Average cost of standard, double strand (steel bucket) Bucket elevators. Standard detachable chain — buckets spaced 15 ins.

monly known as the engineering chain and the combination chain, a chain with malleable iron links and steel pins.

Figs. 17, 18 and 19 give the average cost of standard bucket elevators with steel buckets and two strands of detachable link chain, buckets spaced 12 ins., 15 ins. and 18 ins. apart respectively. Table V gives factors for multiplying the average cost of standard, double-strand bucket elevators with steel buckets when the aver-

TABLE V. STANDARD BUCKET ELEVATOR EQUIPMENT FACTORS

Equipment	Factor
Malleable iron buckets and combination chain	1.78
Malleable iron buckets and standard chain	1.57
Malleable iron buckets and high grade rubber belt	1.50
Steel buckets and combination chain	1.20
Steel buckets and standard detachable chain	1.00
Steel buckets and high grade rubber belt	.92

age cost of some other combination of standard equipment is desired. For instance, a 75-ft. bucket elevator with 20-in. by 6-in. steel buckets attached to two strands of detachable link chain at intervals of 18 ins. would cost about \$950 (see Fig. 19). A similar bucket elevator equipped with malleable iron buckets and combination chain would cost about \$1,691 (950 × 1.78).

A bucket elevator which is kept in good condition requires very little attention after it is started up, but care must be taken that the elevator boot does not become clogged, that unwieldy lumps of material do not find their way to the buckets, etc., so that a labor charge of about four cts. per in. width of bucket is not in-

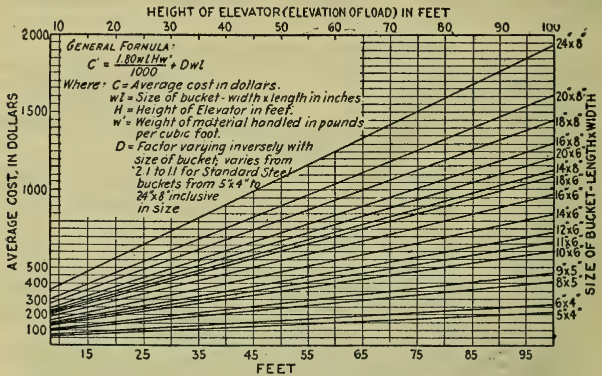


Fig. 19. Average cost of standard, double strand (steel bucket) bucket elevators.

frequent. Such a charge should cover the periodical inspections and may be taken as a fair amount for the labor expense. The expense for incidental supplies, such as grease or oil for lubrication, is naturally quite high in the case of bucket elevators, owing to the unavoidable dust which is raised and which tends to clog up the oil holes of grease cups unless they are well supplied with lubricant; it will average close to 1.5 cts. per h.p. per hr.

Depreciation of bucket elevators is not only comparatively rapid, but varies considerably with the service demanded of the equipment and the class of equipment comprising the installation. Standard elevators with steel buckets and detachable link chains, subject to the service common in a manufacturing plant where the elevator is in fairly constant use, contract an annual depreciation expense approximating 33⅓% on the cost of the buckets, 20% on the balance of the equipment. Malleable iron buckets, unless subject to unusually severe service, contract a yearly depreciating expense of about 20%, while the depreciation chargeable to a well cared for combination chain should not exceed 10% per year. The depreciation on the belt of an elevator employing such equipment

for holding the buckets, if of high-grade rubber and duck construction, should average about 20% in elevators in frequent use.

Notwithstanding the quite dissimilar rates of depreciation of different types of bucket elevators, the average net depreciation expense contracted is very nearly the same, quite irrespective of the class of equipment entering into the construction of the elevator, high-grade materials of their respective classes being employed in the various types. That is, the yearly depreciation charge contracted by a well cared for bucket elevator with malleable iron buckets and combination chain is just about the same as that contracted by a similar elevator with steel buckets and detachable link chain, or by a similar elevator with high-grade

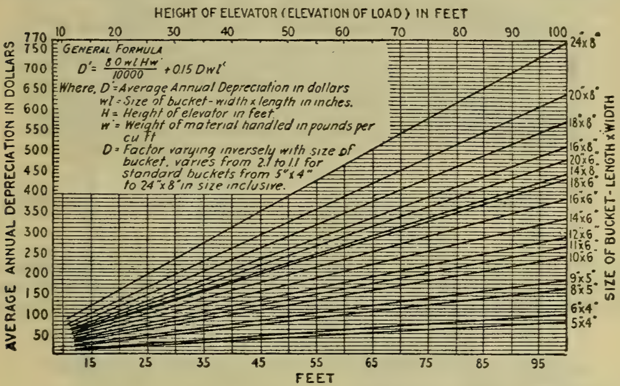


Fig. 20. Average depreciation of standard bucket elevators — buckets spaced 12 inches.

rubber belting for supporting the buckets, although the respective rates of depreciation of various component parts is quite different. Figs. 20, 21 and 22 graphically depict the annual depreciation charge contracted in the average manufacturing plant in which the bucket elevators are properly selected and economically used. The general formulas given on the respective figures enable the depreciation charge to be rapidly calculated in installations in which the elevators are equipped for handling material other than fine coal or ashes.

Bucket elevator installations are subject, naturally, to the usual burden of interest on investment, insurance, taxes, etc., constituting the fixed charges contracted by any investment in mechanical equipment. This burden usually amounts to about 8½% per year of the initial cost of the equipment (6% for interest, 1% for insurance and usually about 2% on the three-quarters of the initial cost for taxes).

In charging up the various expenses contracted in operating a

bucket elevator it is customary to charge up depreciation in proportion to the number of hrs. per year in which the elevator is in actual operation. A year being taken as 2,500 working hrs. This

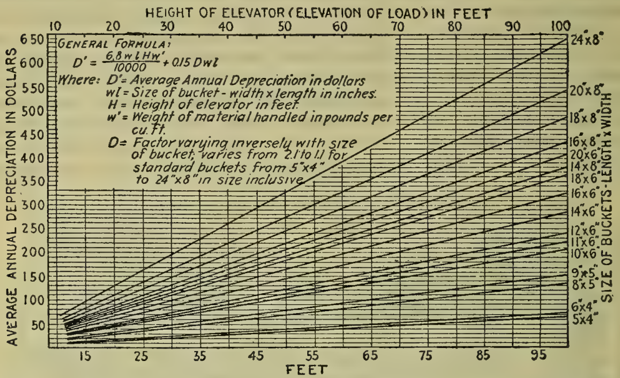


Fig. 21. Average depreciation of standard bucket elevators — buckets spaced 15 inches.

is permissible, as the rate of depreciation during operating hrs. is comparatively high, and though there is a certain degree of depreciation contracted during hours of idleness, such deterioration

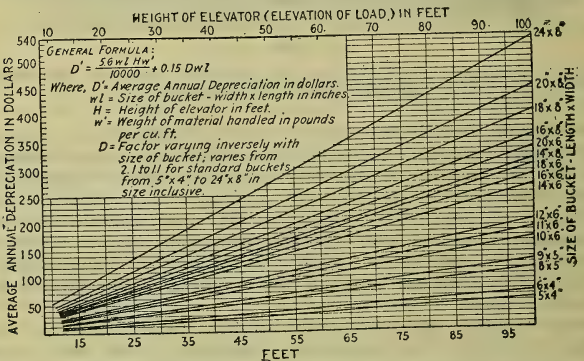


Fig. 22. Average depreciation of standard bucket elevators — buckets spaced 18 inches.

is negligible compared to that taking place while the elevator is in actual operation — providing the equipment is not to remain idle most of the time.

Bucket Conveyors. The bucket conveyor consisting of a succession of buckets attached to two matched strands of endless chain, which can be run in a horizontal path as well as in a vertical plane, represents a combination of bucket elevator and conveyor which possesses all the advantages of the elevator and performs the functions of a conveyor over horizontal stretches.

The buckets for this type of apparatus may be of almost any proportions; they may be rigidly attached to the chains, or may be of the pivoted construction so that they remain in an upright

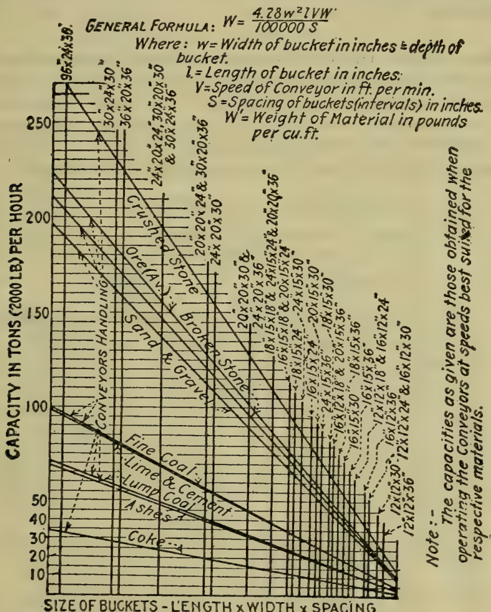


Fig. 23. Capacities of standard bucket conveyors economically loaded and operated.

position throughout their travel, excepting at the points where they are tripped to discharge their load. The proportions of the buckets are now fairly well standardized in practice, however, and the economic speeds at which the conveyors should be run are well established.

Table VI gives the economic speeds for various materials for which this type of conveyor is well adapted.

At the economic speeds recommended, the capacities of the usual standard sizes of conveyors with buckets spaced as commonly found in practice are given in Fig. 23.

TABLE VI. ECONOMIC SPEEDS FOR BUCKET CONVEYORS FOR VARIOUS MATERIALS

Material	Advisable speed, ft. per min.
Coke	40
Broken stone (coarse)	50
Lump coal, run of mine	50
Ashes	60
Lime and cement	60
Ore (average)	70
Crushed stone	70
Sand and gravel	70
Fine coal	80

This chart shows the excellent choice of equipment readily procurable on the market for capacities up to 35 tons of fine coal per hour, or corresponding capacities for other materials. This diversity of standard conveyors in the smaller sizes makes the economic selection of proper size for a specific task of particular importance as well as one involving careful judgment.

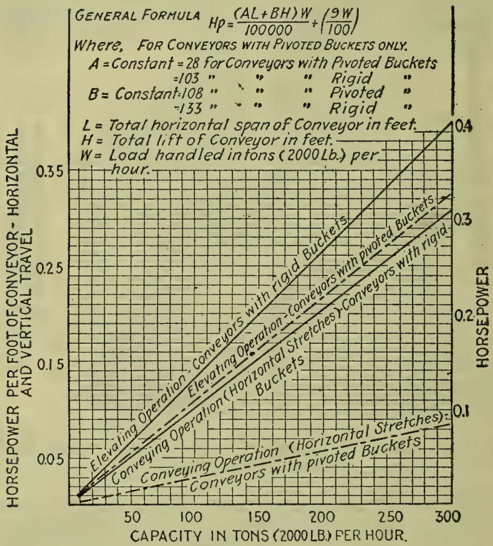


Fig. 24. Horsepower requirements of bucket conveyors.

As in the case of bucket elevators, bucket conveyors are perfectly balanced so that the power requirements comprise simply that required for the elevating operation, for the conveying operation, and to overcome the frictional resistance of the equipment, etc. In bucket conveyors of the type in which the buckets are

rigidly attached to the chains, considerable power is consumed in dragging the buckets through the supply of material in the feeding trough, etc.; and in the type in which the buckets are attached to the chains so as to maintain an upright position while in any plane, power is required for operating the "reciprocating feeder" for loading the buckets.

Fig. 24 shows the power requirements for both types of bucket conveyors, those with rigid buckets and those with pivoted buckets. The power required for the elevating operation does not differ so greatly in amount for the two types, but the difference is quite marked in the conveying operations, conveyors with the buckets rigidly attached to the chains being virtually flight conveyors of an inefficient type and therefore extremely lavish in the use of power. Bucket conveyors with pivoted buckets are economical in

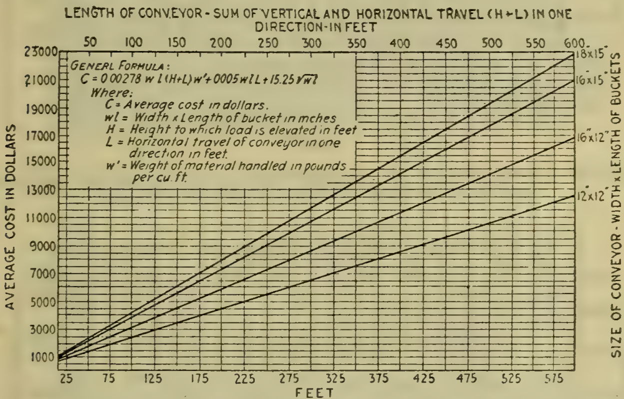


Fig. 25. Average cost of standard bucket conveyors for handling fine coal in rigid buckets, spaced 18 inches.

the use of power and are rapidly displacing the less efficient though very much cheaper conveyor with rigid buckets.

The spacing of the buckets not only materially affects the capacity of bucket conveyors but also has a considerable effect upon their cost — the buckets constituting an important item in the cost of the equipment. Figs. 25 to 32 inclusive depict the average cost of standard bucket conveyors; the first four charts refer to conveyors with rigid buckets, and the latter four to similar conveyors with pivoted buckets, the bucket spacing being 18 ins., 24 ins., 30 ins. and 36 ins. respectively. These charts are derived from cost data from average installations — as usually encountered.

The general formulas given on the various figures permit ready calculations to be made of the average costs in cases where the vertical lift or the horizontal travel are abnormal — that is, where the ratio between the length of the two operations differs con-

siderably from the usual run of installations. The formulas also enable the cost of equipment for handling unusually heavy or extremely light materials to be ascertained. In such special cases,

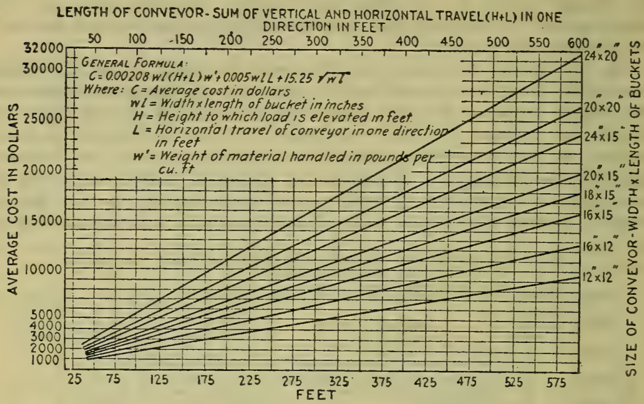


Fig. 26. Average cost of standard bucket conveyors for handling fine coal in rigid buckets, spaced 24 inches.

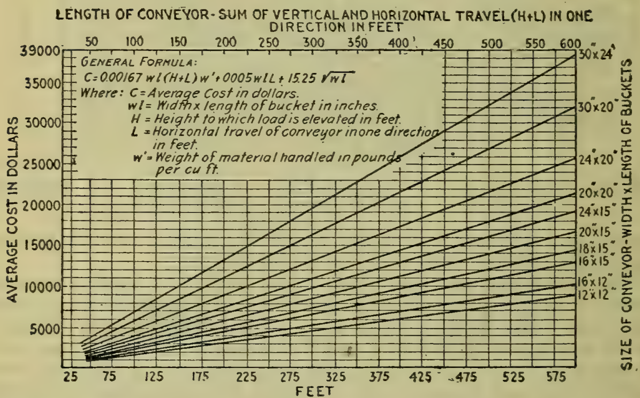


Fig. 27. Average cost of standard bucket conveyors for handling fine coal in rigid buckets, spaced 30 inches.

heavier or lighter equipment is frequently advisable. For ordinary service, the results obtained from the figures are accurate enough for practical purposes. The initial cost of this type of conveyor is high compared to almost any other type of conveyor or elevator,

so that a considerable variation in initial cost has comparatively little effect upon the net cost of operation per ton.

Bucket conveyors require somewhat more attention during opera-

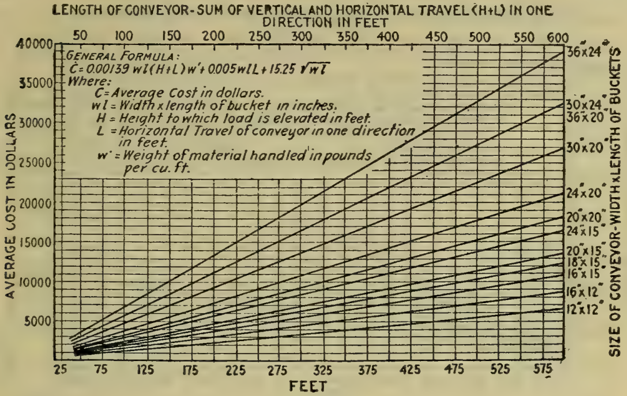


Fig. 28. Average cost of standard bucket conveyors for handling fine coal in rigid buckets, spaced 36 inches.

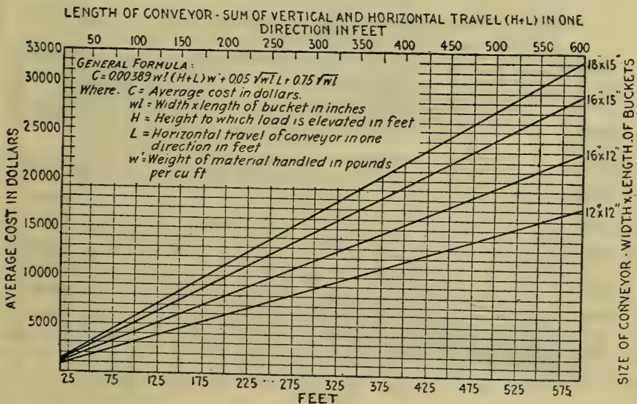


Fig. 29. Average cost of standard bucket conveyors for handling fine coal, pivoted buckets, spaced 18 inches.

tion than do some of the other systems of conveying machinery. In addition to the necessary periodic inspection, bucket conveyors with rigid buckets must have the gates in the horizontal troughs opened and closed as required, and conveyors with pivoted buckets

necessitate some attention to the reciprocating feeder and for setting and shifting the tripping devices. The average expense for the less efficient type of construction will average about 5 cts. per

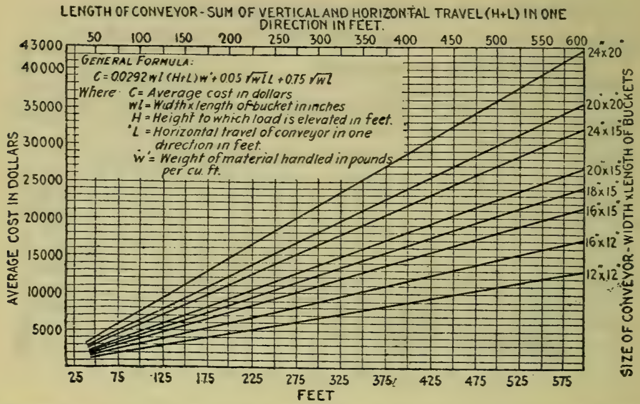


Fig. 30. Average cost of standard bucket conveyor for handling fine coal, pivoted buckets, spaced 24 inches.

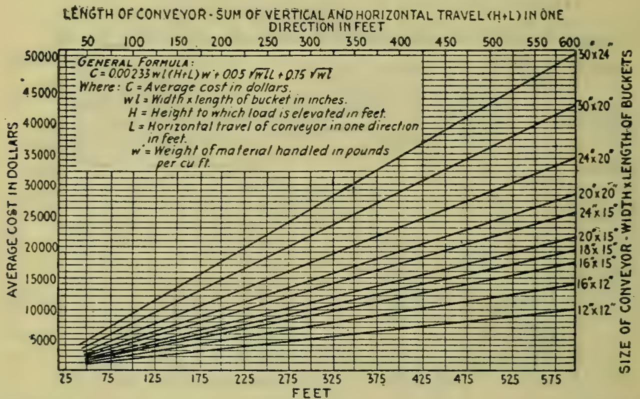


Fig. 31. Average cost of standard bucket conveyors for handling fine coal, pivoted buckets, spaced 24 inches.

hr. per in.-width of bucket, and for the conveyors with pivoted buckets in the neighborhood of 4 cts. per hr. per in.-width.

Incidental supplies vary closely in cost with the power consumption of the apparatus; in the case of bucket conveyors with

rigid buckets it averages about 1¼ cts. per h.p. per hr., and for conveyors with pivoted buckets in the neighborhood of 1 ct. per h.p. Such charges cover not only the expense of the necessary grease or oil, waste, etc., but also the application of the lubricant. The question of lubrication is important in this type of conveyor and should be attended to regularly.

The complexity due to the variation in bucket spacing of the two types of conveyors, so apparent in the consideration of average initial costs, is still further accentuated in the matter of depreciation, as the component parts of the two types of conveyors deteriorate at quite different rates. The ordinary yearly depreciation of the buckets for the conveyors with rigid construction aver-

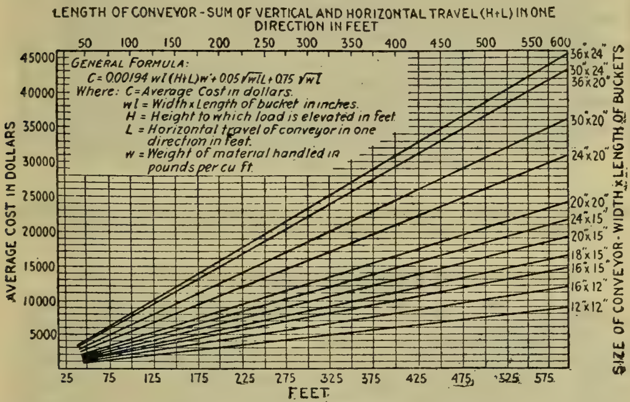


Fig. 32. Average cost of standard bucket conveyors for handling fine coal, pivoted buckets, spaced 36 inches.

ages close to 33⅓%, while that of the pivoted types of buckets should not exceed 20%, unless the service to which the conveyor is subjected is unusually severe. The depreciation on the chains does not vary to any great extent, averaging about 15% per year. Chains for rigid buckets must be heavier because of the greater amount of power they have to transmit, and though subject to more of a scouring action than the chains for the pivoted type of conveyor they withstand the abrasive wear better on account of their greater weight.

The horizontal troughs of the conveyors with rigid buckets wear out about as rapidly as do the rigid buckets themselves, while the rails, etc., of the more efficient construction do not contract a depreciation of more than 10 or 15% per year — sometimes even less. The balance of equipment for either type of conveyor should not show depreciation at a greater rate than about 10% per year.

Figs. 33 to 40 inclusive graphically depict the average annual

depreciation contracted by bucket conveyors when handling such material as fine coal in the manufacturing plant; the first four figures showing the average deterioration of conveyors with rigid

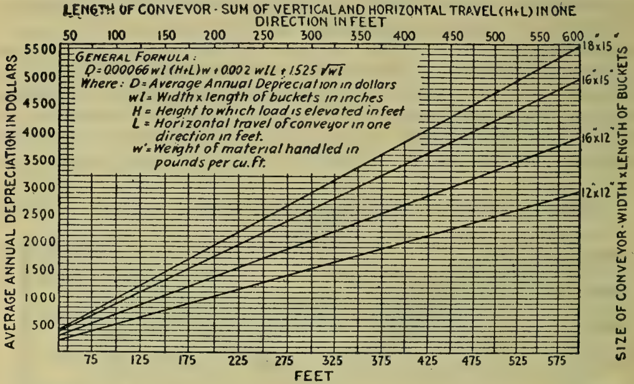


Fig. 33. Average depreciation of standard bucket conveyors handling fine coal in rigid buckets, spaced 18 inches.

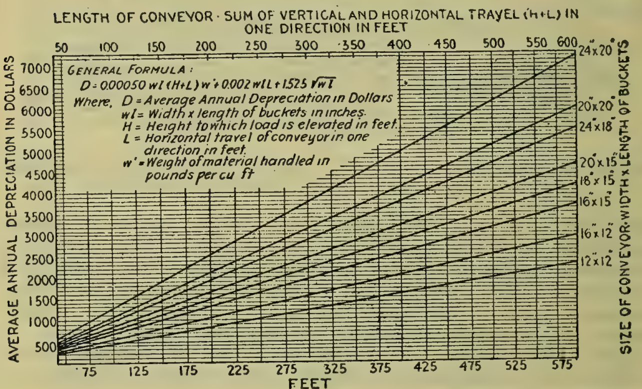


Fig. 34. Average depreciation of standard bucket conveyors handling fine coal in rigid buckets, spaced 24 inches.

buckets spaced 18 ins., 24 ins., 30 ins. and 36 ins. apart respectively. The other four figures give similar data for conveyors with pivoted buckets.

The general formulas given on the various figures permit the

rapid calculations of average depreciation contracted by conveyors of unusual proportions, conveyors handling other material than fine coal, etc. Usually the data obtained from the figures direct

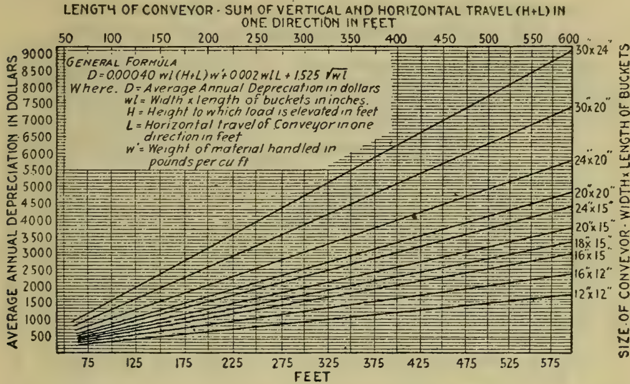


Fig. 35. Average depreciation of standard bucket conveyors handling fine coal in rigid buckets, spaced 30 inches.

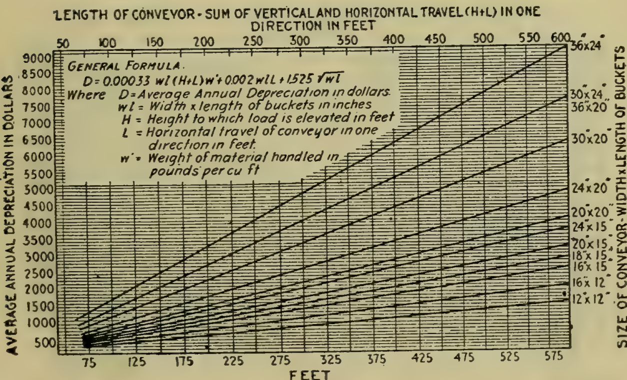


Fig. 36. Average depreciation of standard bucket conveyors handling fine coal in rigid buckets, spaced 36 inches.

are sufficiently accurate for all practical purposes, however, for in the case of bucket elevators it is customary to charge up only such proportion of the annual depreciation that is represented by the actual number of hours in which the system is in productive

operation. In the case of bucket conveyors with rigid buckets, this practice of apportioning the depreciation is justified by the comparatively high depreciation, providing that the conveyor is

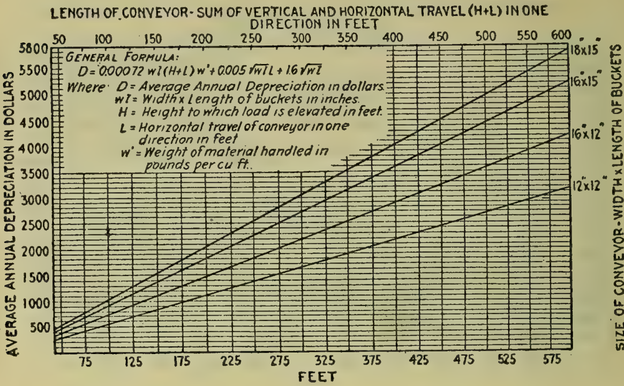


Fig. 37. Average depreciation of standard bucket conveyors handling fine coal in pivoted buckets; spaced 18 inches.

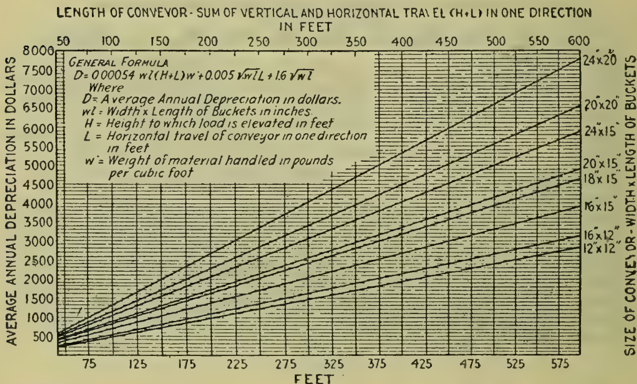


Fig. 38. Average depreciation of standard bucket conveyors handling fine coal in pivoted buckets, spaced 24 inches.

in use a reasonable number of hours each year; but in the case of conveyors with pivoted buckets, such practice is only legitimate when the plant is in active operation at least 60% of the working hours of the year — i. e., from 4 to 5 hrs. each working day.

In installations in which the conveyor is not used more than about 1,500 hrs. per year the depreciation charge of bucket conveyors with pivoted buckets should be figured on such usage.

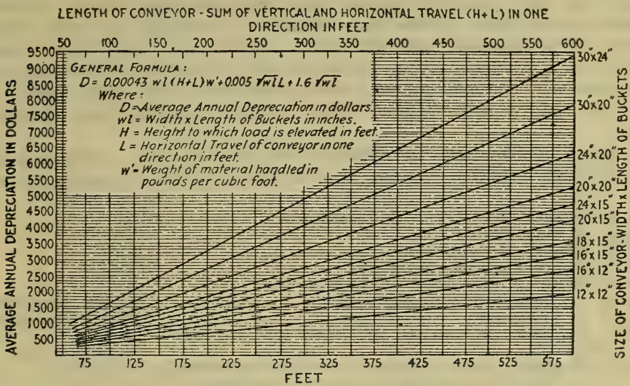


Fig. 39. Average depreciation of standard bucket conveyors handling fine coal in pivoted buckets, spaced 30 inches.

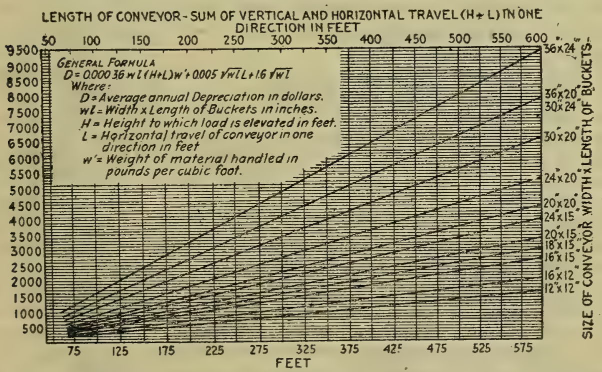


Fig. 40. Average depreciation of standard bucket conveyors handling fine coal in pivoted buckets, spaced 36 inches.

Test of Motor-Driven Coal-Conveyor System. L. A. Quayle in Power, March 7, 1916, gives the following test on the coal and ash conveyor installed at the Fairmount pumping station, Cleveland, Ohio, as made to determine whether the motors and conveyor conformed with the specifications upon which they were purchased.

The main conveyor was of the traveling-bucket type. The buckets were of compressed steel, counterbalanced to hold them in a horizontal position, and they overlap when traveling longitudinally. The cross conveyor is of the endless-belt type and conveys the coal from the hopper into which the cars dump (in the space to the right) to the main conveyor, a distance of 10 ft. The ashes were dumped from the boiler ash hoppers into small cars, which were elevated to the floor above by a hydraulic elevator and dumped into the ash hopper. From here the ashes were conveyed upward into a large hopper, from which they slide into railroad cars.

Conveyor data and the results of the tests on the conveyor running loaded and also running light are given in the following table:

Total number of buckets in conveyor	173
Pitch of buckets	2 ft.
Total length of conveyor	346 ft.
Total height coal is elevated	55 ft.
Rated capacity of conveyor, tons per hr	40
Speed of conveyor running light	40 ft. per min.
Speed of conveyor running loaded	38.2 ft. per min.
Time required for bucket to return to starting point	9 min. 5 sec.
Type of main- and cross-belt conveyor motors, d.c., 115 volt compound wound, inclosed.	
Full-load rating of main-conveyor motor (57½ amps.)	7.25 h.p.
Full-load speed of main-conveyor motor	775 r.p.m
Full-load rating of cross-conveyor motor (19½ amps.)	2.5 h.p.
Full-load speed of cross-conveyor motor	1,200 r.p.m.
Length of run, running light	27 min.
Length of run, unloading coal	2 hr. 28 min.
Net weight of coal in car No. 216,435	97,900 lbs.
Net weight of coal in car No. 216,082	98,300 lbs.
Total coal unloaded	98 tons
Rate of unloading, tons per hour	39.78
Input to both motors, conveyor running light	115 v. 19 amp.
Input to both motors, conveyor running light	2.18 kw.
Current input to both motors, conveyor running loaded	113 v., 41 amp.
Average input to both motors, conveyor running loaded	4.63 kw.
Rated continuous input to both motors	8.85 kw.
Actual input in per cent. of rated input	52.3
Max. temp. of bearings on main motor	120 deg. F.
Max. temp. of bearings on cross-belt motor	116 deg. F.
Max. temp. rise of main motor windings	25 deg. C.
Max. temp. rise of cross-belt motor windings	20 deg. C.
Max. allowable temp. rise of main- and cross-conveyor motor windings	55 deg. C.
Theoretical b.hp. required to elevate the coal and give it a velocity of 38.2 ft. per min.	2.22 b.hp.
Efficiency of the conveyor, assuming an efficiency of 80% for main-conveyor motor and 78% for cross-conveyor motor	45%

The conveyor handled slightly less than its rated capacity during the test, owing to the buckets not being completely filled.

The ratio of current input running light (2.18 kw.) to current input running loaded (4.63 kw.) is 47%, which represents ap-

proximately the efficiency of the conveyor and checks within 2% the b.h.p. method, which was used in obtaining the efficiency of 45% shown by the test.

A Bucket Conveyor Machine for loading wagons from open piles, consisting of a gasoline engine driven inclined conveyor mounted on a wagon truck, is built by the Link Belt Company of Philadelphia, and is sold at $850. Engineering News, Feb. 22, 1912, gives the following data on its use:

Comparative observations of the machine in use in a coal yard and of hand loading show the following costs per ton:

MACHINE LOADING

	Cost, cts.
Interest	2.55
Maintenance	1.25
Depreciation	2.12
Power	0.37
Team and driver	5.00
Yard helper	1.25
Total	12.54

HAND LOADING

	Cost, cts.
Team and driver	15
Yard helper	5
Total	20

This is based on loading only 10 tons of coal per day for a year of 200 days; interest is taken at 6%, maintenance and repairs at $25, depreciation at 5%, power at 10 cts. per kw.-hr., team and driver at 45 cts. per hr., yard helper at 15 cts.

When desired, the head chute is made, without extra cost, with a screen plate. The extra cost of screening is then nothing compared with about 6.6 cts. by hand, making the total saving on a ton of screened coal 14 cts.

These figures are for a very small use of the loader — about 10 minutes of actual operation. The ton costs for power, team and men are fixed, but the other costs decrease with increasing use. If 50 minutes' average actual operation for a day can be secured, then the costs per ton for loading and screening drops to 7.8 cts. and the saving per ton amounts to 18.8 cts. The annual saving for the smaller use (unscreened) amounts to $149 ($281 for screened coal); for the larger use it rises to $1,240 for unscreened and $1,880 for screened coal. It is evident that the machine would pay for itself in a year in a medium-sized yard. The figures quoted are for handling coal, but they should be about the same for handling broken stone, etc.

Suction Conveyors. Reginald Trautschold in Industrial Management, Nov., 1916, gives a system of conveying ashes in large power plants, and to a somewhat lesser extent of handling fine coal, which has been developed to a high state of perfection during the past ten years, using the rush of air to a storage tank in which a partial vacuum is maintained by a high speed exhaust fan. The

conveyor proper consists simply of a section of heavy cast-iron pipe in which small intakes are located before each boiler (in ash conveyors) to which the ashes are simply fed and are sucked in by the inrushing air through the open intake, the conveyor duct being connected directly to the exhaust storage tank. A somewhat similar arrangement is also satisfactorily in use for handling fine coal to temporary storage tanks. From these tanks the coal is subsequently distributed to other storage, by other systems of conveying machinery.

This pneumatic system of handling materials possesses many desirable features. It has also several peculiarities which are of interest from an engineering standpoint. The system is an expensive one to install and requires a considerable supply of power for a relatively small capacity; but on the other hand, it calls for practically no individual labor expense and is extremely convenient and cleanly, solving the ash problem, which is so often an annoyance in the manufacturing plant.

As the material handled by a suction conveyor is carried in a state of suspension, the capacity of the system is not high. A 4-in. conveyor (diam. of pipe, or conveyor duct) carries only about 2½ tons of ashes per hr., while the largest size employed, the 12-in. conveyor, only about 23½ tons per hr.

The capacities of standard suction conveyors of the different sizes when handling fine coal or ashes are given in Table VII. When handling other material the capacity of the installation can be readily ascertained by the general formula

$W = 0.0385\ k\ d^2$, where
W = Capacity of the conveyor in tons per hr.
d = Diam. of conveyor duct in ins.
k = Weight of material handled in lbs. per cu. ft.

In the consumption of power, suction conveyors present one of their distinct peculiarities; practically, the length of the conveyor (the conveyor duct) has no appreciable effect upon the consumption, other than a slight increase due to greater leakage through the intakes, leakage which can be controlled to a great extent. This peculiarity is due to the fact that after a certain degree of vacuum has been created throughout the system, no more power is required to maintain such a vacuum in a long conveyor than in a considerably shorter one. The leakage through intakes which are not tightly closed tends to destroy the vacuum, but such leakage, even in a long conveyor with a number of intakes, is slight compared to the inrush of air through the open intakes through which the conveyor is fed. The long conveyor requires a somewhat longer time in which to create the required degree of vacuum than is required by a shorter conveyor, but the volumetric contents of the conveyor duct per unit length is small compared to the contents of the exhausted storage tank. Quite an appreciable increase in the length of the conveyor, therefore, has very little effect upon the time required to secure the state of vacuum necessary for the successful operation of the system.

Another peculiarity of the suction conveyor is that the character of the load has no appreciable effect upon the consumption of power. The degree of vacuum maintained is the important thing: the weight of material handled in no way affects the power consumption.

In a 10-in. conveyor it takes just as much power to handle about 17 tons of ashes as it does to handle about 23 tons of fine coal per hour.

TABLE VII. CAPACITIES, POWER REQUIREMENTS, AND COSTS OF STANDARD SUCTION CONVEYORS

Diameters in ins.	Capacities in tons per hr. Ashes	Capacities in tons per hr. Fine coal	Average h.p. required for exhaust fan	Approximate average cost in dollars
4	2.5	3.7	9	2,300
6	6.0	8.3	20	5,200
8	10.3	14.8	35	9,300
10	17.0	23.1	55	14,500
12	23.5	32.3	80	21,000

Table VII gives the average power requirements of standard suction conveyors when handling any kind of material such as may be successfully conveyed by such apparatus. A 12-in. suction conveyor requires a supply of about 80 h.p. to maintain the required degree of vacuum and such a conveyor would have a capacity when handling ashes of only about 23.5 tons per hr., or require nearly 3.5 h.p. for each tone of ashes carried.

By far the most expensive item of equipment for a suction conveyor is that represented by the powerful exhaust fan required. The storage tank, with its system of water spray for quenching hot ashes, etc., is also an expensive item and just as costly for a short conveyor as it is for a long one. The conveyor duct is comparatively inexpensive, so that the average cost of a complete installation is little affected by the length of the system. Furthermore, the system is still relatively new, so that the average costs may be considered as practically independent of the length of the system and as governed almost entirely by the size of the conveyor (the diam. of the conveyor duct).

Table VII gives the average cost of complete suction conveyor installations of ordinary sizes. The systems are expensive, but their convenience and cleanliness do much to compensate for their high initial cost.

Practically no additional labor charge is contracted in the operation of a suction conveyor. In fact, the duties of the boiler men are reduced rather than increased by such a system for handling ashes. No labor charge need therefore be made against the system when employed for handling ashes; nor, for that matter, when fine coal is handled by the conveyor. In the matter of incidental supplies also, little expense is contracted. The bearings of the exhaust fan, etc., have to be lubricated; there is some expense entailed in the supply of quenching water for the hot ashes, and

there are the usual incidental supplies required in keeping the fan and other mechanically operated parts in proper condition, but that is about the extent of the legitimate expense for supplies — amounting in all to about 1 ct. per h.p.-hr.

Suction conveyors promise to be long lived if properly cared for. The chief item of depreciation is represented by the expense contracted for new elbows at points where the direction of the conveyor duct changes. Such elbows, or their back wearing blocks, wear out rapidly on account of the destructive abrasive action of the rapidly moving load carried in suspension and forcibly projected against any surface deflecting a direct course. The exhaust tanks in suction conveyors handling ashes deteriorate through the corrosive action of wet ashes, but except for these localized points of heavy deterioration a suction conveyor well withstands wear and tear. A conservative depreciation charge, one that is perforce arbitrarily chosen on account of the meagreness of reliable data available, is 10% of the initial cost of the system per year.

The system is subject to the usual fixed charges, consisting of interest on investment, insurance, taxes, etc., say 8.5% of the initial cost.

Steam Jet Ash Conveyors. A system for handling ashes from the boiler grates that is even of more recent origin than the suction conveyor consists of a conveyor duct, similar to that employed in the suction system of ash handling, leading to an elevated storage tank, but utilizing a steam jet taken from the boiler to create the rush of air through the conveyor duct for carrying the ashes, in place of the partial vacuum used in the suction system. The economy of this system is dependent upon the value of the steam utilized by the conveyor — the conveyor duct and the storage tank being comparatively inexpensive and adding no great burden of fixed charges to the installation.

Steam Consumption and Capacity. Careful tests conducted in a plant equipped with this system of ash handling showed an average steam consumption of about 265 lbs. per ton of ashes removed. At 20 cts. per 1,000 lbs. of steam, this would place the steam expense of the system at about 5⅓ cts. per ton of ashes handled. Adding a fixed burden of 25%, a conservative rate, would bring the net cost of handling ashes by the steam jet ash conveyor to about 6⅔ cts. per ton — a figure which compares quite favorably with that contracted by the more complicated system.

Operation of the Automatic or Gravity Railway consists in releasing a car with its load on a down grade on a trestle and stopping it by means of a counterweight of the counterbalance, which is so adjusted that it will allow the car to reach its destination over the bin or dump, where it is dumped by means of a tripping block. Then the momentum of the car having been spent, and its weight reduced, the counterweight falls back to its former position. In doing so the car is given sufficient momentum to carry it back to the point for receiving another load.

The standard types of car are built of one and two tons' capacity with the ridge in the center so that all the material will discharge simultaneously and equally and without danger of overturning. The sides are fastened to each other so that one side cannot open unless the other side opens equally at the same time.

A plant in which an automatic railway effects important economies is that of T. F. Quinlan, New York, described by A. E. Michel in Engineering and Contracting, May 15, 1912. Twenty-five thousand tons of coal are handled annually. The coal is hoisted by means of an electric hoist from the canal boats in ⅓-ton tubs, on a mast and gaff, to an automatic railway car by which it is distributed in the yard.

With the previous equipment, the coal was hoisted by horse power and trimmed into the stock pile. The old equipment cost $1,750, the new one $2,800. The unloading capacity with the old plant was 120 tons per day; with the new machinery the capacity is 200 tons per day, an increase of 80 tons.

The power is purchased by meter at 5 cts. per h.p.-hr., and costs less than 7 mills for each ton of coal hoisted and delivered to the car.

The labor required to operate the new plant in taking the coal from the vessel to the stock pile, is as follows: Three shovelers are employed in the hold of the vessel, one man operates the electric hoist, another dumps the coal into the car, weighs it, and attends to the automatic railway.

The cost of handling to the stock pile, interest and depreciation included, was, with the old plant, 17¾ cts. per ton; with the new plant the cost is 7¼ cts., the comparative operating costs being analyzed below.

NEW PLANT

Capacity 200 tons.	Per day.
3 shovelers, at $1.50	$ 4.50
1 hoister, at $2	2.00
1 man to dump, weigh and tend automatic car, at $1.50	1.50
Electric power, oil, waste, etc.	2.00
Interest and taxes yearly, 10 per cent	2.24
Depreciation, yearly, 10 per cent	2.24
(Two last items based on a year of 125 days' work.)	
	$14.48
Daily cost per ton in stock pile	7¼ cts.

OLD PLANT

Capacity 120 tons.	Per day.
2 shovelers, at $1.50	$ 3.00
3 carts, horses and driver, at $3	9.00
1 hoisting horse and driver, at $3	3.00
2 trimmers, at $1.75	3.50
Interest and taxes yearly, 10%	1.40
Depreciation, yearly, 10%	1.40
(Two last items based on a year of 125 days' work.)	
	$21.30
Daily cost per ton in stock pile	17¾ cts.

This difference of 10½ cts. per ton on 25,000 tons makes an actual saving of $2,625 each year; thus every 13 months the cost of the new plant is saved in reduced pay roll.

Comparative Cost and Value of First Quality and Second Quality Hemp Rope. To determine the relative value of first and second quality of Manila rope the following data were compiled by the Plymouth Cordage Company:

	1st quality	2d quality
Length of rope in coil	1,250 ft.	1,070 ft.
Wt. of coil with lashings	97 lbs.	97 lbs.
Wt. of lashings	1 lb.	3 lb.
Assumed price per lb.	12 cts.	9 cts.
Comparative price per 100 ft.	93 cts.	82 cts.
Breaking strength	2,907 lbs.	1,450 lbs.
Comparative value (estimated)	12 cts.	5⅜ cts.

The coils were accurately weighed and measured and a number of pieces of each were tested for strength upon a reliable testing machine, the above results being obtained from the various weights and measurements.

The Life of a Wire Rope and the Effect of Oiling Thereon. Mr. W. D. Hardie in Engineering and Mining Journal, May 31, 1902, says that in some tests of greased and ungreased wire rope by Mr. Biffart two lengths of the same size and manufacture of rope were run over pulleys, the oiled lengths making 38,700 bends, as against 16,000 for the unoiled, before breaking. In other tests unoiled rope passed 74,000 times over a 24-in. pulley as against 386,000 times for the oiled rope. This illustrates the value of lubricants in keeping down costs of rope service.

Cost of Locomotive Cranes.

15-ton, 8-wheel type, standard gauge revolving locomotive crane, with 46-ft. steel boom and cables for hoist.

Crane shipped on own trucks.

Cost of works....................................$6,000

15-ton, 4-wheel type, standard gauge revolving locomotive crane, with 38-ft. steel boom and cables for hoist.

Cost f. o. b. cars at work....................................$4,850

Equipment for above cranes.

One 15-ton capacity swivel hook-block....................$ 50
One 1½ yd. clam-shell bucked.............................. 450

Capacity, Cost, and Operation of Locomotive Cranes. Cranes are built in sizes ranging from 3 to 60 tons capacity; the lightest ones being used chiefly around industrial plants and the larger ones for special purposes, such as bridge erection, etc. The best all-around crane for maintenance of way work is the 8-wheel crane of 20 to 30 tons capacity. Such a crane will cost from $7,000 to $8,000. The cost of operation depends on the number of days worked, the kind of work, etc., it being evident that a crane loading ballast will require more repairs than one doing light work in a

storage yard. However, the average cost of operation will be about as follows:

Interest	$ 2.00
Depreciation	2.00
Repairs	2.00
Fuel	2.50
Supplies	0.50
Labor	6.00
Total	$15.00

This is somewhat higher than is usually claimed, but it is probably a fair estimate. Where fuel is cheap and wages low, it may be reduced somewhat but it is usual to underestimate such items as depreciation and repairs. Depreciation and repairs have been figured on the basis of a crane being kept in service 20 years, but that in the meantime it will have been completely rebuilt once. The daily rate is based on using the crane 200 full days during the year.

What a crane will earn depends upon the class of work it is doing, and the amount saved depends upon the method superseded. For instance, a crane will not switch cheaper than a switch engine, it will not excavate or handle material cheaper than a good stiff-leg derrick, it will not drive piles cheaper than a good piledriver, or compete with any other good machine designed for special purposes. However, when its adaptability is taken into consideration, the fact that it may displace several machines (on account of being able to command a large territory) makes its value evident.

It is when the use of a crane is compared with manual labor that its great saving is shown. Figures have been obtained from a large number of sources and while they show considerable variation in general it may be claimed that a crane will save, as against hand work, as follows:

	Saving, per day
Handling scrap and other material with a magnet	$40
Handling coal and other material with a clam shell bucket	40
Handling lumber and timber	30
On general construction work including switching	40

From these figures it will appear that a crane may pay for itself in a year's time.

A few comparative costs, selected at random, follow:

Material handled	By hand, cts.	With crane, cts.
Scrap, ton	0.20 to 0.25	0.02 to 0.06
Coal, ton	See note	0.05 to 0.10
Timber, M. ft.	0.40 to 0.50	0.12 to 0.20
Lumber, M. ft.	0.40 to 0 50	0.25 to 0.35
Piling, lin. ft.	0.004	0.002
Cast iron pipe (loading), cwt.	0.032	0.016
Cast iron pipe (unloading), cwt.	0.021	0.012

NOTE: The cost of handling coal is not given, as coal handled in any great quantity by hand generally has some labor-saving device, such as elevated tracks, etc.

The saving in money is not the only saving that can be credited to the crane, as the liability of personal injuries is much less where heavy material is handled by mechanical means.

A few typical examples of crane work follow:

A large locomotive boiler weighing 25 tons has been picked out of a river bed, hoisted 60 ft. and loaded on a car in 25 minutes. By hand it would have taken two or three days and in this case a work train would have been necessary to handle the car.

A stiff-leg derrick has been set up alongside a bridge and put into use in three hours. Without a crane it would take all day to unload and place the engine and derrick ready for setting up.

A tower 100 ft. high has been set up with a temporary boom extension in less time than would have been required to rig a gin-pole to do the erection.

At the Panama-Pacific Exposition there are a large number of statues ornamenting the buildings. These were placed very cheaply with a locomotive crane, the boom of which had been extended to over 100 ft. This enabled the crane to reach practically all locations, and the statues were set up quickly and without damage. To have rigged poles to handle each one would have taken a great deal more time and would have cost much more.

These examples might be continued indefinitely, but others will readily suggest themselves to the practical man. In general, however, it may be claimed that a crane will do hoisting where tracks are available in less time than it will take to rig up any other device.

The Chicago, Milwaukee & St. Paul Ry. has a number of self-propelled locomotive cranes ranging from 5 to 15 tons capacity, the latter size being most generally employed. The first cost of such a crane is from $6,500 to $7,500. The following data give the range of the cost per day:

Interest	$1.08	to	$ 1.37
Depreciation	1.08	to	1.80
Repairs	0.26	to	1.00
Fuel	0.65	to	0.83
Supplies	0.12	to	0.15
Labor	4.40	to	5.85
Total	$7.59	to	$11.00

These figures are gathered from different localities with varying labor scales and costs of fuel and for cranes employed on different classes of work. The labor item only covers the men actually operating the crane and not the crew needed incidentally in handling material or the cost of a night watchman, which would be necessary in a majority of cases.

The general storekeeper in the Milwaukee shops of this company uses a locomotive crane with a magnet almost exclusively for handling scrap, and gives the total cost per day of operating it as $9.10. He states that he is able to accomplish an amount

of work with the crane equivalent to what would require from $50 to $60 by hand labor.

Locomotive cranes are used at the company's two principal bridge yards, which serve as distributing points for bridge material on the eastern lines and also in handling bridge material on track elevation work in Chicago and Milwaukee. At Tomah, Wis., the cost of operating a locomotive crane unloading and handling piles and bridge timber, including four laborers, which are all that are required in addition to the men on the crane, is $13.45 per 10-hour day. The cost of an ordinary yard crew is $14.25 per day, and a locomotive crane is able to accomplish the work of two yard crews.

The following are some comparisons of the cost of handling by hand and by crane:

	By hand	By locomotive crane
Timber	$0.42 per M.	$0.12 per M.
Reinforcing steel	0.24 per ton	0.11 per ton
Piling	0.004 per ft.	0.002 per ft.

The cost of operating a 10-ton crane, estimated on a basis of 300 working days per year, is itemized as follows:

Coal, 875 lbs. at $7	$3.17
Valve oil	0.08
Black oil	0.01
Hard oil	0.01
Crude oil	0.01
Cotton waste	0.01
Boiler washing	0.22
General repairs	0.33
Heating crane shed	0.23
Interest on investment, 5 per cent	1.01
Depreciation, 7 per cent	1.41
Total	$6.49

The above data do not include labor, concerning which the following statement was made:

A saving of 50% in the cost of labor is made by using a crane for handling heavy timber, piling and other heavy materials. A saving of 50% of switching service is made by using a locomotive crane.

By the use of such a crane a saving of approximately $15 per day is made over and above the expenses of upkeep, interest on investment, depreciation, etc.

Mr. Eggleston of the Erie R. R. states that one of their ordinary cranes complete cost $13,300. Interest, depreciation, repairs, fuel and supplies cost per year approximately $3,650 (with an average of 300 working days). He also states that a crane with a magnet will handle as much scrap in a day as 50 laborers; as much timber, piling, etc., as 15 laborers, and as much miscellaneous bridge and building material as 10 laborers. It is invaluable in the placing of structures and structural material.

The above machine weighs 170,000 lbs. It has a piledriver attachment and can operate a drag scraper or a clam shell. Each

movement is independent of all others. In turning the maximum speed is three revolutions per minute, while in propelling on straight and level track the speed is 300 ft. per minute. It is capable of handling, under same conditions, 20 loaded cars.

Equipped with a No. 2 "Arnott" steam hammer the crane can drive piles 34 ft. from center of track at the rate of 130 blows per min. Two tons of coal and 2,000 gals. water will operate it continuously for 10 hours. It requires 2 men to operate, and 6 men will change from boom to piledriver in 3 hours, and the reverse in about 4 hours.

Cost of Handling Lumber in a Railway Shop by a Locomotive Crane Compared with Hand Work (Engineering and Contracting, July 27, 1910) as given by J. F. Slaughter in a paper before the Railway Storekeepers' Association. The following comparisons were presented:

First, in unloading and piling lumber from open cars, Mr. Slaughter finds it costs $6 per car to handle back and forth and properly to assort them on ways of their respective lengths. This same work can be done with a crane for $1.40 per car, or a saving of $4.60.

Car and engine bolsters cost to handle by hand $5 per carload of seventy-five; these can be handled by locomotive crane for 75 cts., or a saving of $4.25.

One hundred 4¼ by 8 axles — by hand $5.50, by crane $1.50, saving of $4. Mounted wheels to axles — by hand 75 cts. per car, by crane 17 cts., saving 58 cts.

He also found in handling scrap that the cost by hand for an average of 100 cars is $7 per car; with the crane it is $2.83, or a difference of $4.37 in favor of the latter.

Mechanical Handling in Storage Yards. There is a general tendency to equip yards with labor-saving devices, chief among which are the various types of cranes in use for piling, hauling and storing bulky materials. There are 4 types of cranes used for this purpose, described by R. C. Cram in Electric Railway Journal, Dec. 23, 1916, viz., stiff-leg derricks, guy derricks, jib cranes and gantry cranes. The stiff-leg type is the one in most general use, and one or more of these will be found almost indispensable in yards of all but the smallest roads, as the operation is simple, the range of use greater and the cost nominal in proportion to its serviceability.

A derrick with a capacity of 10 tons can be made and erected complete without motors for about $500. This includes labor and all fittings. This is a stiff-leg derrick located in a moderate-sized yard, the Summerfield yard of the Connecticut Company at Bridgeport, Conn. It is operated by means of a motor car, hence no other hoisting machinery is required with the derrick itself. The use of the motor car obviates the necessity for the purchase and maintenance of hoisting apparatus.

A 15-ton. wooden stiff-leg derrick with iron fittings is said to have cost as follows in 1913: Lumber, $256.23; iron, $213.52; paint, $3, and labor $35.25, a total of $508.

For yard use only it is probable that a derrick car of the boom-crane type has the greatest range of use, while for combined yard and road use the jib-crane type will be found best. The one particular advantage of the latter in road work is the non-interference with overhead work. Both types are, of course, designed for electrical operation. These equipments cost from $6,000 to $7,000 complete, ready to run.

From Table VIII it is evident that the crane has saved more than $2,200 per year, and therefore paid for itself in a little more than 3 years. A crane of the boom type has been found to save its cost in 1 year as compared with manual labor.

TABLE VIII. SAVING EFFECTED IN FOUR YEARS BY USE OF 3-TON PILLAR CRANE CAR ON ELECTRIC RAILWAY SYSTEM

Number of tons handled	Cost of handling: Without crane	Cost of handling: With crane	Total saving
4000 tons miscellaneous	$1.00	$0.25	$3.000
3324 tons load on cars	.75	.20	1,828
3324 tons to yard	1.00	.25	2,493
6340 tons unloaded	.50	.20	1,902
6340 tons to job	.75	.25	3,170
			$12,393
Cost of crane car, ready to run	$7.000		
Depreciation, 5%, 4 years	1,400		
Interest, 5%, 4 years	1,400		
Upkeep, 2½%, 4 years	700		
			$3,500
Net saving 4 years, 1 car			$8,893

In conjunction with the use of cranes in yards there is a device in use for handling ties with the crane at the Sixty-third Street dock of the Brooklyn Rapid Transit system which reduced the cost of handling from 1 ct. to 3 mills per tie, incidentally reducing the handling force from a crew of 9 men and 1 foreman to 2 men and a crane operator. There has also been a great reduction in accidents and the ties may be piled much higher, thus saving ground space. The cost of these tie-bales is between $50 and $60 each.

Another saving effected through the use of machinery has been made in the handling of granite paving blocks. It was found that handling the blocks entirely by hand cost 22 cts. per ton, which has been reduced to 7 cts. per ton with the aid of machinery.

Installation and Operating Costs of Cranes. Coal received in barges is unloaded most economically by a mast-and-gaff rig, or some form of hoisting tower, the former when the capacity required is small and the latter when a heavy tonnage has to be handled.

Fig. 41 depicts a typical layout of a mast-and-gaff rig for unloading coal barges at a plant of moderate size described by

Reginald Trautschold in Engineering Magazine, July, 1916. The coal is raised from the barge by an ordinary steam-operated mast-and-gaff rig equipped with a clamshell bucket, and is discharged into an elevated hopper which feeds the automatic dump cars of a gravity railway about 500 ft. long. The coal is stored in piles along the path of the railway from which it is reclaimed as required for the power house. Such an installation has a handling capacity of about 50 tons per hr. and if operated a reasonable number of days per year will unload barges and store the coal for a total cost of less than 4 cts. per ton. This cost is calculated as follows: At 50 tons per hr., in an average yearly operating period

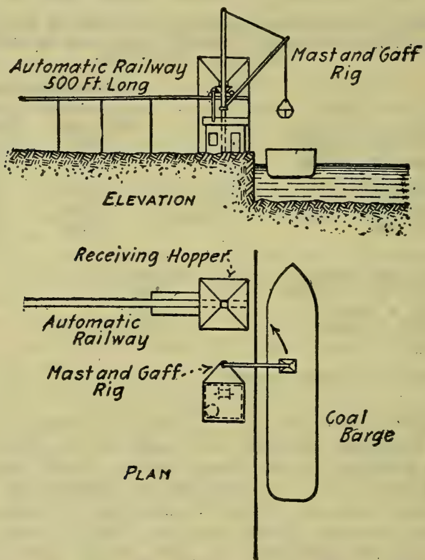
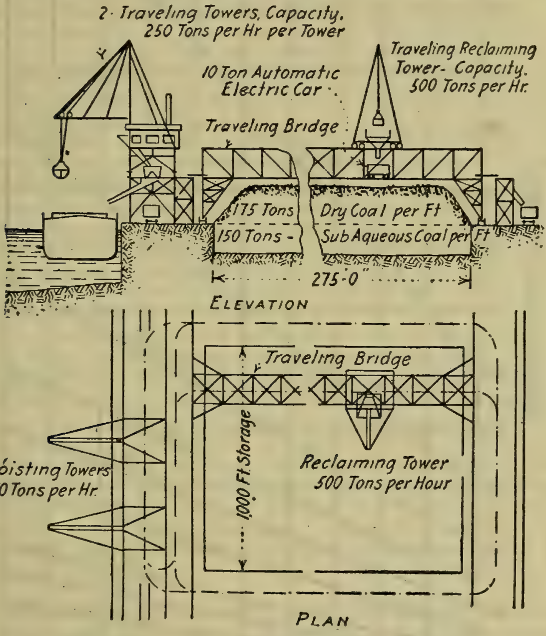


Fig. 41. Mast-and-gaff rig and automatic railway.

of six months, equivalent to 160 ten-hour shifts, there will be handled 80,000 tons. The unloading equipment cost $6,000. Fixed charges on this at 10% are $600, equivalent to 0.75 cts. per ton. The operating charges amount to 2.5 cts. per ton. The storing equipment cost $2,000; calculated similarly, the fixed charges on this are 0.25 cts. per ton, while the operating charges are 0.42 cts. The total of these four items is 3.92 cts., the total cost per ton of handling.

Fig. 42 illustrates an installation of considerably greater capacity, which will unload barges more cheaply and convey the coal nearly three times as far to storage. Three traveling hoisting towers,

steam operated, are mounted upon an elevated trestle for unloading the barges and transferring the coal to a system of industrial cars, which convey it to the vicinity of the power house. The cars discharge to other conveying equipment serving the plant, or the coal may be stored in piles along the elevated trestle upon which the cars run. The average cost of operating this system, based on handling 1,200,000 tons of coal per year, that is 750 tons per hr. for 160 ten-hr. days, is less than 3 cts. per ton. The figures used to derive this result are a first cost for the unloading equipment



Figs. 42 and 43.

Fig. 42. Traveling hoisting towers, steam operated, with car trestle.
Fig. 43. Traveling hoisting towers with traveling bridge and reclaiming tower.

of \$160,000, and an unloading operating charge of 0.7 cts. per ton; a first cost for the conveying equipment of \$85,000 and a conveying operating charge of 0.25 cts. per ton, the total handling cost per ton being 2.91 cts.

A more elaborate arrangement of equipment of somewhat less capacity is shown in Fig. 43. Two hoisting towers mounted on an elevated trestle unload the barges and load 10-ton automatic

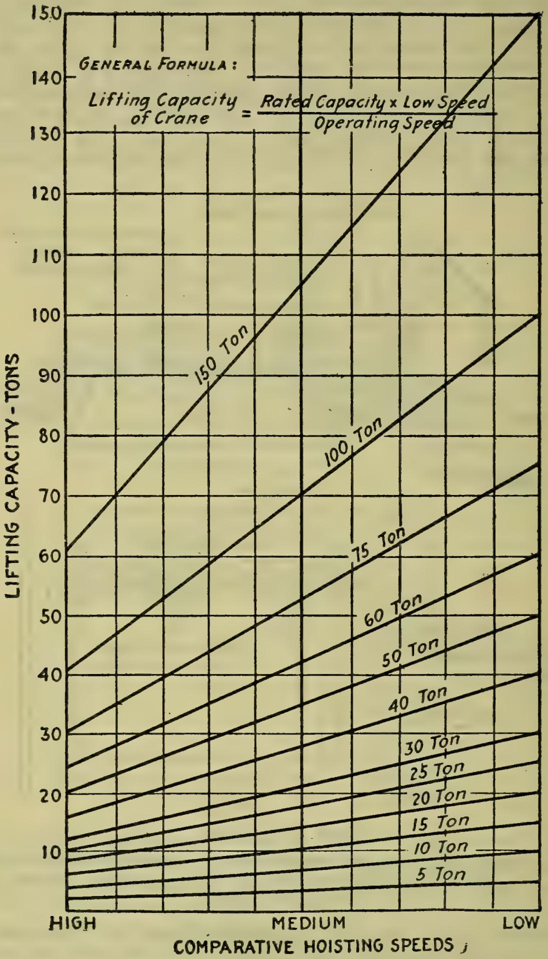


Fig. 44. Lifting capacity of standard overhead electric cranes, at high, medium, and low speeds.

electric cars; the cars discharge their load along a traveling stocking bridge or directly to other cars at the further end of the bridge. These cars convey the coal to the power house. The coal distributed to storage by the traveling bridge is reclaimed by a hoisting tower mounted on the bridge and traveling over it. The capacity of this latter tower is sufficient to handle all the coal that can be unloaded by the two towers on the water front, the capacity of the system, both for storing and reclaiming the coal, being 500 tons per hr. The average net cost of handling coal to and from storage is about 6½ cts. per ton, a part of which can be saved by purchasing coal during depressed markets, since the storage capacity of the plant is large. The first cost of this installation is $100.000 for the unloading equipment, $105,000 for the conveying equipment and $160,000 for the reclaiming equipment. The operating charges for unloading, conveying, and reclaiming are respectively, 0.7 ct., 0.25 ct. and 1.10 cts. The subaqueous storage virtually doubles the storage capacity without detriment to the coal; in fact, under-water storage is frequently to be recommended for soft coals.

Overhead cranes are customarily rated according to their lifting capacity, their chief task, but this is sometimes misleading, since the question of speed of hoist bears as much relation to the capacity of a crane as does the weight it is capable of lifting. The lifting capacity is at the maximum, at the minimum hoisting speed and decreases directly as the hoisting speed increases. This frequently governs the selection of a crane, for it is seldom that a crane is called upon to handle its capacity each trip. Most trips are made without a full load, permitting, or rather necessitating, a corresponding increase in speed in order to realize the true economic value of the crane. Customarily an electric crane is equipped with three fixed speeds, low, medium, and high. At low speed, the crane is capable of handling its rated load, while at higher speeds the normal load of the crane is reduced. Fig. 4 shows the relationship between the lifting capacity of usual standard sizes of overhead cranes and their three respective speeds. An ordinary 30-ton crane at low speed, for instance, can handle within 5 tons of the capacity of an ordinary 60-ton crane when operated on middle speed.

The price of a particular crane built by a certain manufacturer may be taken as unity and the price of his other cranes expressed in proportional amounts. The prices of all manufacturers do not, of course, agree, nor are all cranes of the same capacity and span built by any one manufacturer equally costly, but the comparative costs for similar cranes for similar service should not differ to any great extent. Presented in graphic form such a comparative cost price list is given in Fig. 45, the basis of comparison being the cost of a medium-speed, 5-ton crane of 25-ft. span, arbitrarily taken as unity.

At the present time, owing to the high price of materials and of labor, a 5-ton, medium-speed, overhead electric crane of 25-ft. span would cost in the neighborhood of $4,250, so that (from

Fig. 45) a 30-ton crane of the type considered in the example in the selection of motors would cost 2.56 × \$4,250 = \$11,000. Should the cost of the 5-ton crane be but \$3,500, a fair figure during normal

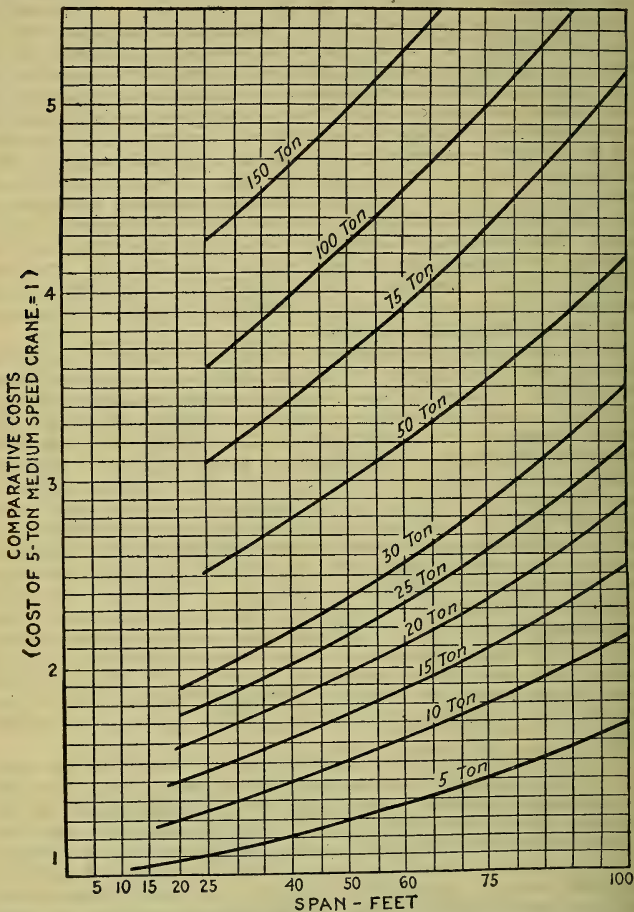


Fig. 45. Comparative prices of standard overhead electric cranes based on the cost of a 5-ton medium speed crane as the unit.

times, the average cost of the 30-ton crane would be about \$9,350.

Depreciation of overhead electric cranes is usually figured at 5%, a safe figure, since there are many installations of well cared

for cranes which have been in more or less constant operation for 15 or 20 years, and which are apparently in as good shape as the day they were installed. Repairs should not average more than 2% per year at the outside; interest on investment, insurance and taxes at the customary rates would bring the total charge to 15.5% and the fixed charges per day on a 30-ton crane costing \$11,000 would be \$5.68, figuring 300 working days per year.

Almost any overhead electric crane found in a manufacturing plant can be operated by one man with some occasional slight service from the regular working force of the plant. The crane-man would command a wage of about 35 cts. per hr., and in the efficiently managed plant his time would be chargeable against the crane while it was in actual operation only. The assistance rendered by other workmen would not entail an expense of more than 15 cts. per hr. on the average, so that a very generous labor charge for the crane would be 50 cts. per hr., this charge applying with equal fairness to almost any overhead electric crane found in a manufacturing plant. The expense for oil, waste and other incidental supplies, together with the expense of occasional careful overhauling and cleaning, may be taken as varying directly with the total power requirements of the crane. A conservative rate would be 0.1 ct. per motor h.p.-hr. The average consumption of electricity including that required for running the crane without load as well as when productively operated is, in kw. per hr., usually about one-half the total power requirements of the crane expressed in horsepower.

The average net cost per day for operating a 30-ton, 60-ft. span, medium-speed, overhead electric crane, assuming an average daily operation of 5 hrs. on 300 days per year, would be about \$13.92, current being valued at 2.5 cts. per kw. This is arrived at as follows:

Cost of crane, \$11,000. (Fig. 46, \$4,250 base.) Motor horsepowers:

Hoisting	35	(previously derived)
Trolley	10	
Bridge	40	
Total	85 h.p.	

Fixed charges per day:

Operating charges per day:

$$\frac{11{,}000 \times 0.155}{300} = \$\ 5.68$$

Labor,	$0.50 \times 5 =$	2.50
Supplies,	$0.001 \times 85 \times 5 =$	.43
Current,	$0.5 \times 85 \times 0.025 \times 5 =$	5.31
Net cost per day		\$13.92

An average of ten trips per hour with a mean load of 20 tons, 1,000 tons handled per day, would place the net cost of employing the crane for the work at less than 1.5 cts. per ton handled.

Overhead electric cranes are frequently employed for outdoor service, such as unloading coal cars and carrying the coal to ele-

vated hoppers feeding boilers or coal bunkers. A typical installation of this character would be one employing a 5-ton crane of 50-ft. span mounted on trestles which would necessitate a 50-ft. lift of loaded bucket and a mean bridge travel of 200 ft. between the coal car and the receiving hopper. The bucket employed would probably be of the clamshell type, of 1½ cu. yds. capacity, capable of picking up an average load of about a ton. The bucket and its contents would place a load on the crane of somewhat more than three tons, so that the hoisting speed of the crane could be higher than if it were called upon to handle its full load of five tons. For a medium-speed standard crane, the economic speed would be about 58 feet per minute.

Elevating the bucket with its load of coal to a position in which it could discharge to the receiving hopper would consume nearly a minute, during which time the bridge travel and any necessary trolley travel could take place, and although the empty bucket could be dropped more rapidly, the coal handling capacity of the installation would not average more than 40 tons per hr. Employing the crane to handle coal 200 eight-hour days per year, equivalent to 64,000 tons of coal per year, would result in a net cost of operation per ton handled of less than 4 cts., the supply of electricity being valued at 2.5 cts. per kw. This is worked out as follows:

Cost of crane..........$5,100 (Fig. 46, $4,250 base.)
Cost of bucket........ 500

Total equipment...$5,600

Hoisting speed, 58 ft. per min.
Hoisting speed at full load, 45 ft. per min.
Trolley speed, 150 ft. per min. (arbitrary)
Bridge speed, 400 ft. per min. (arbitrary)
Coal handled per year: $40 \times 8 \times 200 = 64{,}000$ tons.

Motor horsepowers:

Hoisting $\dfrac{5 \times 45}{16} = 14.0$; say 15 h.p.

Trolley $\dfrac{5 \times 150}{400} = 1.88$; say 2 h.p.

Bridge $\dfrac{(5 + 0.03 \times 50)\ 400}{235} = 11.06$ h.p.; say 15 h.p.

Total .... 32 h.p.

Fixed charges per year:
$5,600 × 0.155 = ...$ 868.00

Operating charges per year:
Labor:
0.50 × 8 × 200 = ...$800.00
Supplies:
0.001 × 32 × 8 × 200 = ... 51.20
Current:
0.5 × 32 × 0.025 × 8 × 200 = ... 640.00

Total $1,491.20

Total net operating cost per year......$2,359.20
(Net operating cost per ton) ....$ 0.0369

Similar analyses of the net operating costs of overhead electric cranes can easily be made for any installation in which the average amount of work to be performed by the crane and the cost of power are known. Failure to know the exact cost of the crane itself does not prevent a conservatively accurate estimate of the net cost of its operation on known work, for quite an appreciable difference in price has really little effect upon the net cost of operation provided that the crane is in fairly frequent use, that it has been economically selected for the work required, and that the expense for power is not unusually low.

Operating Speed, Cost and Capacity of Electric Traveling Cranes. In slecting the equipment for crane service, the user should consider other things besides the mechanical construction, cost, speed, etc. One important consideration which should not be neglected is the amount of material which will have to be handled, the weight of which is considerably below the capacity of the crane. Thurston Kent in Industrial Engineering, April, 1914, states that time studies of machinery operations in a large shop have indicated that on a majority of the work done, approximately 15 mins. was lost on each large machine operation while waiting for the crane.

The prospective user of a crane has a wide range of selection before him, both as regards size and construction of his equipment. The standards of the various makers are such as to permit him to choose a crane of almost any capacity he desires, from 1 ton up to 150 tons. For instance one crane builder writes the author as follows: "The standard capacities of cranes built by us range from 1 ton to 100 tons in single trolley designs, and up to 150 tons in double trolley designs. Their ratings are stepped up about as follows: 1, 2, 3, 5, 7½, 10, 15, 20, 25, 30 tons. Above 30 tons the steps are about 10 tons apart." Another maker offers cranes varying by 5 tons up to 25 tons, and then by 10 ton steps up to 100 tons. Almost any maker will build a special crane, to fit the conditions peculiar to a given installation if desired.

Table IX, prepared by the Alliance Machine Co., Alliance, Ohio, is presented as a general guide to the dimensions of standard cranes. It must be borne in mind, however, that the figures in the table are not to be regarded as final, as local conditions will modify them considerably. For instance, a long-span crane of a given capacity will of necessity weigh more than a crane of the same capacity but of shorter span. This would make a difference in the wheel loads, which in extreme cases, might necessitate a revision of the design of the trucks. The electrical equipment provided for the crane also will have more or less influence on its construction.

Speed of Cranes. The speed of the crane is another point which deserves consideration. It has already been pointed out that the time lost by productive machines while waiting for the crane may be the cause of serious losses to the mill. In a letter to the author, the Northern Engineering Works, Detroit, gives the following notes on crane speeds: A good average speed for moderate

TABLE IX. GENERAL DATA FOR STANDARD ELECTRIC TRAVELING CRANES. BASED ON 60 FT. SPAN, 25 FT. LIFT, WIRE ROPE HOIST

Capacity, tons of 2,000 lb.	Distance runway rail to highest point	Distance center of rail to end of crane, ins.	Wheel base of end truck	Max. load per wheel trolley at end of bridge	Approx. wt. of crane, lbs.	Approx. price of crane
5	5 ft. 8 ins.	7	9 ft. 0 ins.	20,000	40,000	$3,600
10	6 ft. 6 ins.	8	10 ft. 0 ins.	28,000	53,000	4,400
15	6 ft. 7 ins.	8	10 ft. 6 ins.	34,000	56,000	4,800
20	6 ft. 8 ins.	8	11 ft. 0 ins.	41,000	65,000	5,400
25	7 ft. 5 ins.	10	11 ft. 6 ins.	51,000	77,000	6,500
40	8 ft. 1 ins.	11	12 ft. 0 ins.	82,000	95,000	8,200
50	9 ft. 4 ins.	12	12 ft. 0 ins.	47,500*	107,500	10,500

* Has eight track wheels.

standard work for the main hoist is 10 ft. per min. full load. For some very rapid work, this is doubled. When direct current is used, this speed on light loads can be automatically speeded up 2 to 2½ times greater, but this is not done with alternating current. The average bridge speed for cab controlled cranes is 250 to 300 ft. per min. full load, to 300 to 400 ft. light. The usual trolley speed is about 100 ft. per min. with full load on cab controlled cranes. If a crane is floor controlled, it is advisable to reduce the travel speeds to about half the above figures.

The writer, in 1909, compiled a series of notes on cranes. These notes included the following data on speeds, and also Table X herewith. The figures there given appear at this date to still hold true. The usual range of motor sizes is as follows: Hoist, 15–50 h.p.; trolley, 3–15 h.p.; bridge, 15–50 h.p. The speeds at which the various motions are made range as follows, the figures

TABLE X. STANDARD HOISTING AND TRAVELING SPEEDS OF ELECTRIC CRANES

(Pawling & Harnischfeger.)

Capacity, tons (2000 lb.)	Hoisting speed, ft. per min.	Bridge travel speed, ft. per min.	Capacity aux. hoist tons	Speed aux. hoist, ft. per min.
5	25–100	300–450	..	.....
10	20–75	300–450	3	30–75
	10–40	250–350	3	50–125
25	.....	....	10	25–60
			5	40–100
40	9–30	250–350	10	26–60
			5	40–100
50	8–30	200–300	10	25–60
75	6–25	200–250	15	20–50
125	5–15	200–250	25	20–50
150	5–15	200–250	25	20–50

Trolley travel speed from 100–150 ft. per min. in all cases.

being ft. per min.: Hoist, 8–60; trolley traverse, 75–200; bridge travel, 200–600. These speeds are varied in the same capacity of crane to suit each particular installation. In general, the speed of the bridge in ft. per min. should not exceed (length of runway + 100). If the runway is long and covered by more than one crane, the speed may be made equal to the average distance between cranes + 100. Usually 300 ft. per min. is a good speed. For small cranes in special cases, the speeds may be increased, but for cranes of over 50 tons capacity the speed should be below 300 ft. per min. unless the building is made especially strong to stand the strains incident to starting and stopping heavy cranes geared for high speeds.

For purposes of comparison, Table XI, compiled by the Alliance Machine Co., is also given.

TABLE XI. STANDARD FULL LOAD SPEEDS OF STANDARD TRAVELING CRANES.

(Alliance Machine Co.)

Capacity tons 2000 lb.	Hoist speed ft. per min.	Bridge speed ft. per min.	Trolley speed ft. per min.
5	50	400	150
10	25	350	125
15	17	350	125
20	12½	350	125
25	10	300	125
40	10	250	100
50	9	250	100

TABLE XII

Use for which designed	Over-all length, ins.	Over-all diam., ins.	Total wt. of active iron and copper, lbs.	Length of stroke, ins.	Pull at beginning of stroke, lbs.	Voltage	Watts input at end of stroke	Power factor at end of stroke	Factory cost
Relay:									
D.c. . .	3¼	2⅛	2.9	⅛	0.15	110–500	9	. . .	$5.10
A.c. . .	3¼	2⅛	2.9	⅛	0.10	" –550	15	0.39	6.95
Lifting:									
D.c. . .	5	3	8	1	8	" – "	50	. . .	6.40
D.c. . .	11	7	80	3	20	" –500	210	. . .	33.00
A.c. . .	5½	4	10	⅞	7	" –550	30	0.30	8.15
A.c. . .	14	6¼	90	2½	50	" – "	400	0.31	32.00
Brake:									
D.c. . .	5¼	8½	72	⅛	160	" –220	50	. . .	21.00
D.c. . .	6	15	320	5/32	1260	" – "	210	. . .	39.00
Clutch:									
D.c. . .	6½	10	82	⅛	60	" – "	52	. . .	19.00
D.c. . .	7	18	210	⅛	400	" – "	115	. . .	35.00

Costs of Electromagnets. Due to the great variety in the designs, it is not possible to give unit costs of electromagnets. The subject of the most economical magnet design has been discussed by Wikander (Trans. A. I. E. E., 1911, Vol. 30, p. 2019), but unfortunately the most economical design will usually be found not to be suitable for practical purposes, because it results in a magnet which is too long compared to its diameter, and which usually cannot be incorporated in the machine with which it is to be used. Therefore, magnets as they are found in practical application deviate greatly from the most economical design. Also for the same energy output (usually expressed as inch-pounds or foot-pounds) there is as much as a 1 to 3 variation, depending upon the service conditions as to speed of operation, stroke, etc., which they have to meet. Table XII, of costs, weights and dimensions of some typical electromagnets, is given merely as a range guide.

Cost of Handling Locomotive Tires and Heavy Castings by a Magnet and Crane in a Locomotive Shop according to Mr. Mears in a paper before the Railway Storekeepers' Association printed in Engineering and Contracting, June 27, 1910, is represented by the following figures:

Loading locomotive tires:	Per ton
By hand	$0.17
By crane	.08
By crane and magnet	.04

Loading heavy castings:	Per ton
By hand	Almost impossible
By crane	.20
By crane and magnet	.03

The principal reason for the efficient work of the magnet in handling heavy materials is on account of the difficulty of obtaining a good hold upon the heavy castings when they are handled by chains or hooks.

A Specially Designed Traveling Crane for laying a 48-in. gas main on a trestle is described and illustrated in Engineering News, Jan. 22, 1914. Two 45-lb. railroad rails were laid across the caps of the trestle throughout its length on a 5-ft. 4-in. gauge. The pipe was hauled to one end of the trestle with teams and rolled by hand to the other end, where it was lifted and set in place with a traveling crane astride of the last set pipe.

On the average, 29 pipe-lengths a day were laid with this device, using a force of 6 men and a foreman. The calking was done by the gas company with a calking machine, recently come into use. The joints are calked with lead wool, and no special expansion joints in the pipe line are provided. None of the lengths of pipe are set absolutely home in the bells, there being at least ⅛-in. space left for expansion, which the nature of the lead-wool calking permits.

An Electric Motor Truck Crane made by the General Electric

Co. for use in shops and warehouses is described in Engineering News, Dec. 7, 1911, and the following data given:

Five hundred castings aggregating 65,000 lbs. were unloaded from a gondola car in 5 hrs., giving an average of 1.2 lifts per min. A box car was loaded with 64 800-lb. bbls. of plumbago in 25 mins., and 4 cars were loaded in 2½ hrs., the latter work including spotting the cars. This averages 2 bbls. per min. hoisted nearly 5 ft. and swung well inside the car.

Sixty 800-lb. bbls. of plumbago were moved 300 ft. in 1 hr., 1 helper only being required. One hundred and fifty 300-lb. boxes of rubber were conveyed 75 ft. and loaded into a box car in 50 mins., 3 boxes being slung together and a round trip made every min. In a store room, boxes of angle and flat iron weighing about 1,000 lbs. each were carried 30 ft. and stacked in sorted and orderly piles at the rate of 40 boxes an hr. One-ton rocks were

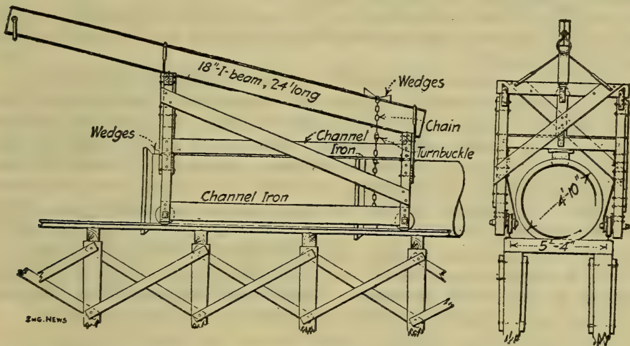


Fig. 46. Details of a specially designed travelling crane for placing 48-in. gas main on a narrow pile trestle over a swamp.

loaded onto trailers from a scattering pile at the rate of 24 an hr., being hoisted 2 ft. and carried about 20 ft. in the operation. Two 1,200-lb. water meters were lifted from a hole 6 ft. deep and carried to the shop bench 1,000 ft. away in 30 mins.

The truck is not arranged to carry heavy loads itself, but is intended for use in towing trailers whenever the distance to be traveled is such that this method is preferable to that of transferring the material in small lots suspended from the crane hook. The limiting distance for economical work without trailers is put at about 400 ft., that is, where large quantities of freight are involved. The truck is designed for a high drawbar pull (2,000 lbs. maximum), to suit it for trailer towing. This pull is about equal to that of a five-ton locomotive on rails, and is sufficient, it is claimed, to handle loads of from five to eight tons on trailers. On account of this high tractive force, the truck can be used for

spotting cars and may prove useful for giving assistance to overloaded wagons or automobiles.

A special form of trailer has been designed for use with this truck, having a capacity of 3 tons. The deck, 12 ft. by 4 ft., is at a height of 29 ins. above the ground. The wheels are 24 ins. in diam., with a 5-in. face and are mounted on roller bearings. A heavy towing tongue is provided with arrangements for easy coupling to the motor truck or to another trailer. It is claimed that the trailers follow truly in the track of the truck, so that no difficuly is found in towing a number of them even around obstructions.

Four trailers is the usual number in a train for long hauls, but this can be varied to suit the conditions. When there is a sufficient amount of work to be done to make it pay, time can be saved by using 3 trains of 1 to 4 cars each. One train is then being loaded and another unloaded, while the third, either empty or loaded, as the case may be, is on the way between. In this way, a maximum of 600 sq. ft. of loading deck can be kept working to its full capacity.

Data of the truck's work with trailers are given as follows:

Six hundred thousand pounds of cotton have been moved one-half mile in a day (10 hrs.), taking 24 bales per load and making a round trip every twelve mins. This gives an average of two bales (600 lbs. each) per min. moved a distance of one-half mile. On a hurry order for cotton, 48 bales (12 tons) were delivered alongside the lighter within 25 mins. after the order was given. One truck using 3 trailer trains of 2 cars each has moved 1,000,000 lbs. of small package freight (canned salmon) 600 ft. in 9 hrs.

The following represents an average week's work at towing trailers in the Bush Terminal, New York, deduced from the logs of a number of these machines operating over a long period:

Number of packages handled	7,570	
Average weight per package	230	lbs.
Total weight handled (900 tons)	1,720,000	lbs.
Average distance packages were moved	900	ft.
Per cent. of total time machine was working	80%	
Packages delivered per working minute	3	
Number of different jobs worked on	30	
Heaviest single load drawn	12½	tons
Cost of operator, interest, depreciation, power	$24.00	
Cost of moving one package 900 ft.	⅓	cts.
Cost of moving one ton (9 packages) 900 ft.	3	cts.

Cost of Hoisting Water in Unwatering Mines. The removal of water from mines by hoisting in tanks is in the nature of a reversion to the methods of the ancients, but with the plants as now operated, with the improvements and changes which experience has shown necessary, the method may be efficient and less costly than pumping.

R. V. Norris in a paper before the Institute of Mining Engineers in 1904 describes fully all details of apparatus and their arrangement, including the following costs:

The costs of the construction of two plants are given in Table

XIII. The plants are at the William Penn Mine of the Susquehanna Coal Co. and Lytle Coal Co's shaft. The costs of the water hoisting plants are charged with their proper proportion of the total cost of the shaft-sinking, head frames, steam lines and boiler plant. The cost of the steam plant is omitted from the lower set of figures because it was available in one case only, and in that was based upon a division of cost among three other hoists.

TABLE XIII. COST OF UNWATERING BY HOISTING

	William Penn water-hoist	Lytle water-hoist
Depth of shaft, ft.	953	1,500
Capacity of tanks, gals.	1,400	2,600
Size of engines, ins.	32 by 48	30 by 60
Diam. of drums, ft.	Straight 12	Cone 10 to 16
Capacity of hoist, gal. per 24 hrs.	2,100,000 (280,000 cu. ft.)	3,750,000 (500,000 cu. ft.)
Best record, gals. per 24 hrs.	2,291,040 (307,000 cu. ft.)	3,772,600 (505,500 cu. ft.)
Cost:		
Sinking and timbering	$20,673.81	$22,641.63
Head frame	4,224.13	3,540.58
Water-hoist engines, foundations and house	15,583.64	29,653.17
Tanks and ropes	2,393.23	3,899.65
Steam line	3,726.12	4,951.17
Boiler plant	....	16,091.76
	$46,600.93	$80,777.96
Cost, excluding shaft sinking and steam plant	$22,201.00	$37,093.40
Cost per 1,000 gal. daily capacity, excluding shaft and steam plant	10.57	9.87
Cost per 1,000 cu. ft. daily capacity, excluding shaft and steam plant	88.08	82.25

The rate at which the plants work is shown in Table XIV. The Lytle shaft during a strike was filled to a depth of 860 ft., the water, amounting to 274,083,500 gals., was hoisted out in 37 days and 4 hrs. Besides the regular water hoist, tanks were used in all of four coal compartments; the plant then consisting of two pairs of 2,600-gal. tanks and one pair of 1,500-gal. tanks; the water hoisted by each was:

TABLE XIV. RATE OF UNWATERING

	Average per day, gals.
Water-hoist	2,977,753
Large coal-hoist	2,803,142
Small coal-hoist	1,431,819
	7,212,724

During one month, 236,906,000 gals. were hoisted an average of 740.6 ft., the boiler plant (12–150 h.p. return tubular boilers and one 500 h.p. Babcock and Wilcox boiler) was devoted exclusively to this work, it burned 4,122 tons of coal and used 6,206,100 gals.

of water, which indicates an average evaporation of 5.55 lbs. per lb. of coal, and about 44,004,000 lbs. of steam at the engines. This gives a duty of 33,260,000 ft.-lbs. per 1,000 lbs. of dry steam; or, 59.5 lbs. of steam for actual h.p.-hr. in water lifted, and 251 lbs. of steam for 1,000 gals. lifted 1,000 ft.

The cost of steam during this month was:

Labor	$ 934.62
Water	496.49
4,122 tons coal at $0.50 per ton	2,061.00
	$3,492.11

Thus 44,004,000 lbs. of dry steam delivered at the engines cost $0.0794 per 1,000 lbs.; equivalent to $0.0198 per 1,000 gals. hoisted 1,000 ft. vertically; or $0.00238 per 1,000,000 ft.-lbs. in water; $0.00472 per h.p.-hr. in water; cost steam only, per year, per boiler h.p. 24 hrs. per day for labor, supplies and repairs $8.57; fuel, $12.30; total, $20.87.

From Oct. 30 to Dec. 5, 1902, the plant of the William Penn No. 2 shaft, which was flooded to a depth of 250 ft., hoisted 112,468,080 gals., using a pair of regular water hoist 32 by 48 in. engines, and a pair of 28 by 48 in. coal engines with 1,440 gal. and 1,320 gal. tanks, the record being given in Table XV.

Total cost, exclusive of steam, was $987.83, or $0.0088 per 1,000 gals. hoisted.

The record for 3 years at the Luke Fiddler shaft is given in Table XV — engines 32 by 48 ins. with 1,450-gal. tanks.

The plant was operated at only ⅓ of its capacity; at full capacity the cost is estimated to average about 2.5 cts. per 1,000 gals. for 960 ft. vertical.

TABLE XV. COST OF HOISTING AT THREE SHAFTS

Plant	Fiddler 3 years		Wm. Penn 37 days		Lytle 1 month	
Depth of shaft	960 ft.		953 ft.		1,500 ft.	
Quantity hoisted, gals.	918,501,200		112,468,080		236,906,000	
Quantity hoisted, cu. ft.	123,079,160		15,070,730		31,745,300	
Average height hoisted	960 ft.		727.8 ft.		740.6 ft.	
Cost of labor repairs and supplies per 1,000 gals.	$0.0114		$0.0088		$0.0071	
Cost of steam per 1,000 gals.	0.0192		0.0146		0.0148	
Total cost per 1,000 gals.	$0.0306		$0.0234		$0.0219	
Total cost per 1,000 cu. ft.	0.2295		0.1755		0.1643	
Estimated cost per 1,000 gals. and 1,000 cu. ft., 1,000 ft. vertical	1,000 gals.	1,000 cu. ft.	1,000 gals.	1,000 cu. ft.	1,000 gals.	1,000 cu. ft.
Labor supplies and repairs for hoisting	$0.012	$0.090	$0.009	$0.068	$0.008	$0.06
Steam	0.020	0.150	0.020	0.150	0.020	0.15
Total	$0.032	$0.240	$0.029	$0.218	$0.028	$0.21
Total cost per 1,000,000 ft.-lbs. in water	$0.0038		$0.0035		$0.0034	
Total cost per h.p.-year, 24 hrs. per day in water	$65.91		$60.71		$58.97	

Table XV also shows a summary of the operating costs of the three plants.

This is about 69% of the average cost of pumping at the collieries of the Lykens Valley Coal Co., where it was \$0.37 and \$0.29 per 1,000 cu. ft. 1,000 ft. vertical, and \$98.11 and \$81.47 per h.p.-year in water for 1901 and 1902.

The Cost of Hoisting in Small Zinc Mines. George S. Brooks in the Engineering and Mining Journal gives the following cost of plant and operation of 2 zinc mines in Wisconsin. Mine A was equipped with cars and a cage, and Mine B had the 1,000-lb. tubs customary in that district.

(Mine A)

Equipment:	
Derrick and foundations, including cable and sheave	\$ 400
Engine housing	50
7 x 10 Duplex geared hoisting engine	700
5 mine cars	125
1 cage	60
Total	\$1,335
Interest and depreciation:	
Interest on \$1,335, 6%	\$ 80
Depreciation on \$1,335, 18%	240
Total for 300 working days	\$ 320

(Mine B)

Equipment:	
Derrick inclosed, including cable and sheave	\$ 480
7 x 7 Duplex geared hoisting engine	470
5 tubs and trucks	110
Total	\$1,060
Interest and depreciation:	
Interest on \$1,060, 6%	\$ 63
Depreciation on \$1,060, 18%	190
Total for 300 working days	\$ 254

At *A* the hoist is set up on the ground about 40 ft. back from the shaft, and the engine is of the horizontal type. At *B* the upright 7 × 7-in. engine is stationed near the derrick top about 10 ft. below the sheave, and located so that the engineer may handle the throttle with one hand, while with the other he can attend to the dumping of the tubs.

Operating Costs:

The following operating costs are the result of monthly averages. In both cases, for the sake of comparison, the same charge is made per h.p. per hr., although in reality there was some 20% difference owing to the excessive line condensation at the *B* shaft. Neither schedule includes cost of administration. The approximate h.p. is computed from the following formula, to which an additional 0.25 h.p. is added for friction and inertia:

$$\text{H.p.} = \frac{\text{gross weight in lb.}}{33{,}000} \times \text{speed in feet per min.}$$

It is given as follows: *A* — Mine run, 1,870 lbs.; cage, 400 lbs.; cable, 108 lbs.; car, 300 lbs.; total, 2,678 lbs.

The hoisting speed per min. is 360 ft. Then

$$\text{H.p.} = \frac{2,678}{33,000} \times 360 + 0.25 \text{ h.p.} = 36 \text{ h.p.}$$

The same calculation applied to the case at mine *B* gives mine run, 980 lbs.; tubs, 175 lbs.; cable, 102 lbs.; total, 1,257 lbs.; hoisting speed per min., 295 ft.

$$\text{H.p.} = \frac{1,257}{33,000} \times 295 + 0.25 \text{ h.p.} = 14 \text{ h.p.}$$

The actual hoisting performance per day of 9 hrs. at *A* is 120 tons and at *B* 100 tons. With forcing, *A* has handled 600 cu. ft. per hr., while at *B* 450 cu. ft. is about the best that can be done.

Hoisting Expense, 9-hr. Shift:

Mine A.

One hoisting engineer	$2.50
One lander	2.25
36 h.p. for 5 hr. at 1 ct. per h.p. per hr.	1.80
Interest and depreciation	1.06
Repairs	0.70
Total	$8.31
Ore hoisted	2590 cu. ft.
Cost per cu. ft.	$0.0032
Cost per ton approximately	0.06

Mine B.

One hoisting engineer	$2.50
14 h.p. for 5 hr. at 1 ct. per h.p. per hr.	0.70
Interest and depreciation	0.85
Repairs	0.70
Total	$4.75
Ore hoisted	2140 cu. ft.
Cost per cu. ft.	$0.0022
Cost per ton approximately	0.044

Both of these cost accounts show what is possible when a steady output is made for a month. The average hoisting expense, month in and month out, has been a few cents above this.

It appears from the comparative figures that the tub is considerably the better on hoisting alone, and until the workings become extended to such a distance from the shaft as to materially increase the tramming costs, it will show a smaller operating expense in working flats. The initial investments in reality show only a difference of $275, which amount deserves little consideration in the matter of a suitable hoisting and tramming equipment.

Cost of Operating a Mine Hoisting Plant. A hoisting plant in operation at the shaft of the Hecla mine had reached its capacity hoisting ore from the 300-ft. and the 600-ft. level. When, there-

fore, the 900-ft. level was opened it was necessary to install a new hoist or to remodel the old one. Electricity from a new plant at Spokane, Wash., made power available at $50 per h.p.-year as against $109 per h.p.-year for steam. It was decided to substitute for the engines a motor drive of sufficient capacity to operate from the 900-ft. level and ultimately to install an entirely new hoist. The description of this plant and the permanent plant which followed it 4 years later and the results of power consumption and cost are given by E. M. Murphy in a paper before the Transactions of the American Institute of Mining Engineers and abstracted in Engineering and Contracting, Oct., 1910.

The motor-generator set of the permanent plant is self-contained, having a cast iron sub-base, four bearings and shaft; the driving element consists of a 450-h.p., three-phase, 60-cycle wound secondary motor to operate between 2,000 and 2,300 volts. The generator is a 450-kw., 525-volt machine with commutation poles to permit its handling full load current at any voltage below maximum. A flywheel is mounted on the shaft. It is 7 ft. 9 ins. in diameter and weighs 29,000 lbs. The hoist motor is rated at 375 h.p. at 500 volts, 60 revolutions per min., and weighs 51 tons. It is directly connected by a flange coupling to the reel-shaft which carries 1,600 ft. of ⅜ in. × 4½ in. flat rope. The skips are 50 cu. ft. capacity, weigh 3,500 lbs. The double-decked cages hang beneath the skips at all times and each cage weighs 2,400 lbs.

Before entering into the cost of operation of the hoist, an explanation of the contract will show on what basis a settlement is made for power consumed by it. The contract runs for a period of five years and is based on a maximum demand as well as a kw.-hr. consumption. It will be noted that it penalizes a better combined power and load-factor than 61%. A power-factor of 100% and a constant voltage of 2,300 volts is assumed in all the calculations of maximum demand. In a contract calling for a maximum demand of 100 kws., a minimum sum of $335 ($3.35 per kw.) is paid each month; this sum entitles the consumer to 43,550 kw.-hrs. (130 for each dollar). At the same time, the maximum of 100 kws. must not be exceeded at any time during the month. In case more than 100 kws. is the maximum, the minimum bill is increased by $3.35 for each kw. in excess. For each dollar of this increase, the consumer is entitled to use 130 kw.-hrs. If the kw.-hrs. used exceed 43,550, the excess is paid for at the rate of $0.0112 per kw.-hr. On the basis of 43,550 kw.-hrs. per month at $335 each kw.-hr. costs $0.00769. This amounts to $50 per h.p. per year. The peak on the hoist never lasts 5 mins., so the power never costs more than $50 per h.p.

As the Hecla mine has but one hoist, the handling of all timbers, waste, etc., as well as the shifts, must be performed by it, in addition to the ore-hoisting. To give an idea of the work the hoist does, Table XVI was compiled for the period of time from Aug. 1, 1911, to Jan. 1, 1912:

In order to determine the cost per ton for power used during actual hoisting, a series of tests was taken, with the following

TABLE XVI. HOISTING PERFORMANCE

ORE HOISTED

	600-ft. level	900-ft. level	1,200-ft. level
Skips	2,241.0	9,968.0	9,961.0
Tons	5,840.0	25,824.0	26,028.0
Monthly average—			
Skips	448.2	1,993.6	1,992.2
Tons	1,168.0	5,164.8	5,202.6

CARS OF WASTE HANDLED

	1,200 to 600	Top to 600	Top to 300
Cars	3,946.0	7,416.0	826.0
Average	789.2	1,483.2	165.2

	Stulls	Wedges	Timbers, lagging and chute
	321,677 ft. b.m.	79 cars	475,140 ft. b.m.
Average	64,335.4	15.8	95,028.0

Power Consumed: 234,760 kw.-hrs., average equals 46,952 kw.-hrs., equals $361 per month. Total cost for power for each ton of output equals $0.0313.

results: From the 1,200-ft. level 32 skips (83 tons) were hoisted in 33 mins., with a kw.-hr. consumption of 142. On the basis of $0.00769 per kw.-hr., the cost of hoisting the 83 tons was $1.092, or $0.0131 per ton. From the 900-ft. level 14 skips (36.4 tons) were hoisted in 11 mins., with a kw.-hr. consumption of 50, and a cost of $0.3854, or $0.01[illegible]5 per ton. From the 600-ft. level 14 skips (36.4 tons) were hoisted in 10 mins., with a kw.-hr. consumption of 40, and a cost of $0.3076, or $0.00845 per ton.

To run the set light for 1 hr. requires 48 kw.-hrs. at a cost of $0.368. In service the set runs continuously during the 24 hrs., with the exception of a period of about 4 hrs. after midnight. After the power is cut off, the set will run for 1.25 hrs., unless it is slowed down by hoisting, or the band-brake on the flywheel is applied. The hoist was guaranteed to maintain one-quarter output of the mine working unbalanced from the 2,400-ft. level (its ultimate depth). In order to test this feature, a load of 1,773 lbs. was added to compensate for the extra weight of cable to 2,400 ft. This weight was obtained by placing a car with the required amount of ore in it on a cage deck. The car was allowed to remain on the cage during the entire time of hoisting. Unbalanced hoisting was maintained at the rate of 11 trips an hr. from 900 ft. for 3 hrs. All temperatures at the end of this time were well within the guarantees. In May, 1911, one of the clutch-arms broke, and the hoist operated unbalanced with entire satisfaction for a period of 20 hrs., part of the hoisting being from the 1,200-ft. level.

The upkeep of the equipment for the 3 years and 8 months it has been in service has been extremely low. The hoist-motor has needed no repairs, while the exciter has had but one new set of brushes. The generator requires about one new set of brushes a year. The motor has been the only source of expense, and like trouble could occur to any motor. Three times it has

suffered a grounded coil during a lightning storm. The winding is a 3-bank concentric winding, and replacement of coils is a tedious affair. A new set of collector-rings was also put on this machine.

The hoist requires but 1 man per shift to operate it. Another advantage of the hoist is its ability to operate for a short time, even though the power be accidentally interrupted. The running-lights in the hoist-room are all lighted from the exciter, which enables the operator to see as long as hoisting can be continued. Without ore, as in handling men, the hoist is capable of making several trips after the power is shut off. This installation has the disadvantage of consuming power, even though the hoist motor is not in actual operation. This is more apparent than it would be if the hoist were operating from greater depths, or handling greater tonnage. The effect greater depth has on the efficiency is shown from the tests. From the 600-ft. level, the cost per 1,000 ft.-tons is $0.014, from 900 ft. it is $0.0116, and from 1,200 ft. it is $0.0109. The effect greater tonnage would have on the cost per ton of output is shown by the following: Assuming that the mine double its output, the kw.-hr. consumption per month would be increased by 17,231, at a cost of $132.59. The total cost for power for each ton of output would be lowered from $0.0313 to $0.0213.

Comparison Between Electric and Steam Hoisting Systems and Between Direct-Current and 3-Phase Systems for Hoisting in South African Mines. H. W. Clayden and S. E. T. Ewing in the Transactions of the South African Institute of Electrical Engineers, Dec., 1916, also printed in Electrical World, April, 1917, compare the Ward-Leonard system and the 3-phase hoisting system with respect to the different requirements of mine hoisting, and reach the following conclusions:

For shaft sinking both systems are equally effective on all points at approximately equal capital cost.

For rock hoisting from one level with tail ropes the relative economy of the two systems depends on the frequency of hoisting; the lower the frequency of hoisting the greater the gain to the alternating-current system, and conversely the higher the frequency the greater the gain to the Ward-Leonard system. The alternating-current system has the lower capital cost. The systems are of equal safety and ease of handling.

For rock hoisting from one level without tail ropes the alternating-current system has lower capital cost, while the Ward-Leonard system has superior over-all economy and is easier to handle.

For rock hoisting from several levels, for raising and lowering men, for lowering supplies, and for dead-slow hoisting the alternating-current system has lower capital cost, while the Ward-Leonard system has the superior over-all economy and is easier to handle.

Comparative efficiency and cost figures are given from practice for three hoisting plants — a 5-ton Ward-Leonard hoist, a 5-ton 3-phase hoist, and a 4-ton steam hoist at 3 different mines. The

h.p. is 500 for the Ward-Leonard hoist, 550 for the 3-phase hoist and 800 for the steam hoist; the size of drums is 10 ft. by 3 ft. 6 in., 10 ft. by 3 ft. 6 in., 9 ft. by 3 ft. 3 in.; the maximum rope speed 2,000 ft., 1,500 ft., 1,500 ft.; the capacity of the skip, 5, 5, 4 tons; the maximum vertical depth of shaft 2,060 ft., 1,583 ft., 1,323 ft.; the maximum length of shaft 3,902 ft., 2,420 ft., 2,072 ft. These figures are near enough to give a fair comparison.

It appears that the Ward-Leonard hoist has a 6.7% higher over-all efficiency than the 3-phase winder; but in the case of the former only 2 shifts are worked and the converter set is shut down for 7 hrs. each day. This set requires 20 kw.-hr. per hour running light, so that comparing the two winders on a 24-hr. service the Ward-Leonard efficiency will be only 3.5% better than the 3-phase hoist.

For the steam hoist only 3 months' accurate figures as to steam consumption are available. For 3 months this hoist required 99 lbs. of steam per shaft h.p.-hr., but this must not be taken as a representative figure for steam hoisting, as owing to the small amount of work done by this hoist the standby losses are exceptionally high. Only a very rough efficiency comparison can be made, and therefore the comparative figures of cost are more important.

The average monthly cost of each of the three hoists over the 3 months April, May and June, 1916, is given in the table, and it is stated that the figures for the next 3 months are practically the same, there being only a difference in the third-place decimal.

TABLE XVII. AVERAGE MONTHLY COST OF HOISTS (1916)

	Ward-Leonard	Three-phase	Steam
Average shaft, h.p.-hrs.	25,436	26,124	20,425
Attendance, oil and engine-room stores, per useful shaft h.p., cts.	0.316	0.322	0.352
Repairs, wages and stores per h.p., cts.	0.194	0.584	0.070
Power, electric and air or steam per h.p., cts.	1,786	2,076	3,492
Total cost per h.p., cts.	2.296	2.982	3.914

The first item, attendance and engine-room stores, includes all engine-room wages and stores except hoist-engine drivers' wages, which are charged direct to hauling and do not come into the power account.

The second item, "repairs," includes all electrical and mechanical supervision, inspection and repairs.

The third item "power," for the electric hoists, includes the cost of electricity and air power. The power required for the brake engines is taken from the general mine air supply, the small compressor in the winding-engine room coming into operation only when the mine pressure drops below 60 lbs. per sq. in. "Power" for the steam hoist includes coal, oil, water, wages and maintenance of the boiler-house plant and is the cost of steam power delivered to the engine house.

Electric Passenger Elevator Systems. William Ehrlich in Elec-

trical Engineering, April, May and June, 1914, gives the following:

To indicate fully the extensive use to which the elevator has been adopted for passenger traffic in large cities, the instance of the Borough of Manhattan in Greater New York is given. There are about 10,000 machines in service, being twice the number that were in operation ten years ago, and these are divided among the different classes of buildings approximately as follows:

5000	elevators	in	office buildings over 10 stories high.
1500	"	"	office buildings under 10 stories high.
500	"	"	loft buildings.
700	"	"	residences.
800	"	"	apartment houses.
500	"	"	department and other stores.
1000	"	"	hotels, clubs, institutions, etc.

Besides these passenger cars, the building systems requiring freight service involve an additional 10,000 machines.

In modern elevator practice William Ehrlich in Electrical Engineering, April to June, 1914, states there are but 2 common types of successful machines in use — namely, the hydraulic and electric elevators. These may both be classified as to the mode of drive or operation and the transmission of power, thereby showing an apparent variety of elevators. The hydraulic type machine may be of the vertical cylinder pattern and also of the plunger type, while the electrical apparatus is either of the drum, worm-gear or gearless traction type, as illustrated in Fig. 47.

In summarizing, it might be well to mention that the commercial or useful life of an elevator and its combined mechanisms seldom exceeds 15 years, and that where remodeling has been resorted to, the electric drum and worm-gear traction has usually been substituted for the hydraulic type in buildings not exceeding 12 to 16 stories, and in higher structures the gearless traction or its modification in the form of an electric "two-to-one" traction elevator has been resorted to.

In narrowing down the question as to the merits of the electric traction elevator and the hydraulic plunger elevator for passenger service in tall office buildings of today, it might be well to note that the new elevator installations, almost without exception, have favored the electric. Not only is the cost of installing the traction 25% to 35% less than the plunger type, but the room occupied by the driving machinery is reduced to a minimum, and, as a matter of fact, may be placed at the head and directly over the elevator shaft. If no local supply of electricity is available on the premises, the public source may be resorted to.

The difficulty with the plunger elevator for high-rise high-speed work lies in the requirement for moving the mass of water and the massive plunger proper, and as this immense weight cannot be readily and smoothly stopped, the result is a sluggishness in starting and stopping. At any rate, it remains an open question as to whether the economic values attached to modern buildings would

favor the installation of the plunger elevator, with its accompanying pumping plant, which necessarily occupies considerable floor space. The only open choice, therefore, would tend to favor the high-rise high-speed electric traction elevator for passenger service.

The figures given in Table XVIII may prove of interest in pointing out the relatively higher operating costs of the different elec-

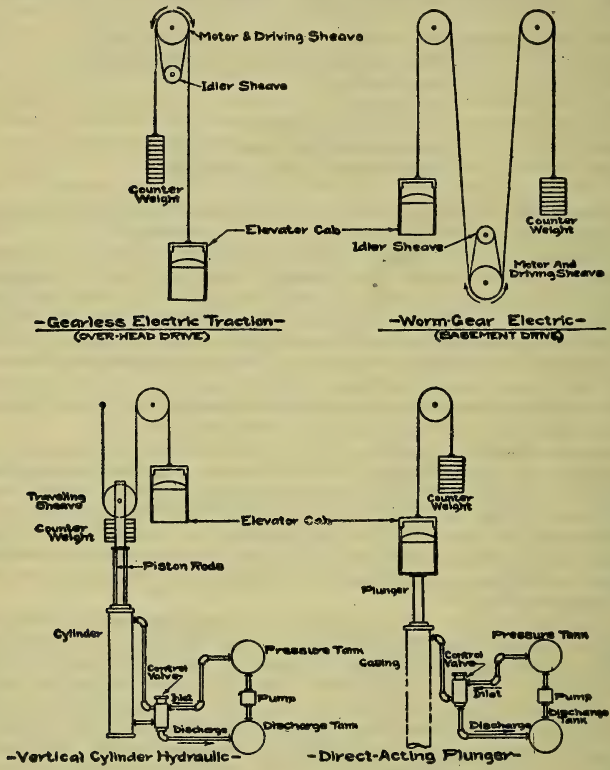


Fig. 47. Types of elevators.

tric types over the vertical cylinder hydraulic and plunger elevators. The values given represent only the cost of labor, power, repairs and supplies. By a close perusal of the amounts listed, it will be confirmed that the economies of the plunger cannot be utilized beneficially in tall office buildings on account of the mechanical difficulties, and in other types of smaller buildings allowing for a

low rise the installation cost becomes exorbitant. If the relatively high first cost of this type of machine were taken into consideration, with an addition for the extra cost in building construction necessary for the space occupied by the pump and tank equipment, the total expenditure on the whole would show no great favor either way.

TABLE XVIII. RELATIVE OPERATING COST OF ELEVATORS

Costs	Office building			
	Traction electric	Worm-gear electric	Vertical-cylinder hydraulic	Direct plunger
Per cent. of rentals	8.5	7.2	6.8	6.5
Cents per car mile	25	22	20	19
Dollars per car per annum	2,100	1,850	1,680	1,600
Per cent. of all operating costs	14.1	12.0	11.3	11.0
	Loft building			
Costs	Traction	Worm-gear	Hydraulic	Plunger
Per cent. of rentals	8.0	6.8	6.5	6.2
Cents per car mile	23.8	20	19	18
Dollars per car per annum	1075	900	860	810
Per cent. of all operating costs	18.0	15.4	14.8	14.0
	Apartment house			
Costs	Traction	Worm-gear	Hydraulic	Plunger
Per cent. of rentals	6.8	6.0	5.5	5.3
Cents per car mile	20	18	17	16
Dollars per car per annum	560	510	480	450
Per cent. of all operating costs	13.6	12.0	11.0	10.6

In explaining the values given in Table XVIII, it should be understood that the figures are computed on a basis of actual records of several buildings that have come to the writer's notice. The general method of comparing records in business buildings is to relate the costs to the total annual income or rental. The total operating costs include the expense in the mechanical, electrical and building departments, covering all costs of labor and material for the maintenance of the different divisions of service. Therefore the annual cost of operating an elevator system is given as a percentage of the gross rentals received, and is further stated as a percentage of the total operating expenditure of the buildings

under consideration. The average cost in cents per car-mile traversed is also given, together with the average annual cost in dollars to pay for the labor in operating and repairing, the necessary power, and the material and supplies required per single elevator.

The efficient operation of an elevator system does not rest altogether on the economic division and disposition of the cars, as the human element becomes one of the main factors. It is self-evident, therefore, that the service of an elevator is limited not only by the different classes of passengers entering, riding and leaving the conveyance, but by the experience of the hall man or "starter" and his ability to understand the demands of the traffic and the personal peculiarities of the elevator operators.

It is now common practice to dispatch the various machines of an elevator system on a predetermined time schedule, thus avoiding to a great extent any confusion or overcrowding that would otherwise arise. It has been well established that the consecutive travel of elevators under schedule operation allows for a highly efficient service, not only in the handling of the traffic, but in the demand for power, which is thereby reduced to a minimum.

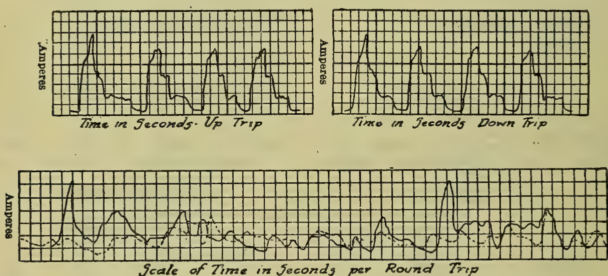


Fig. 48. Recorded current consumption of gearless traction elevators.

The power diagrams, Fig. 48, point to the effect of poor and proper service under different conditions. The upper curve (a) was taken under test conditions and represents the operation of one elevator. The load in the single car is approximately equal to the designed machine balance, both on the up and down trips, and the number of stops corresponds to the average per car mile under actual service in office buildings. This diagram is given mainly to allow for a proper understanding of the combined curve (b) showing the actual round trip operation of a bank of elevators in one of the New York sky-scraper buildings at the early morning hour. The full or solid line curve shows an excessive power demand due to an inconsistent "schedule," the cars having been dispatched by a starter who may be identified by (X), while the dotted or broken line curve shows the more expert handling

under the consecutive dispatching by starter (Y), the same operators running the cars in each case.

Another important consideration is the division so common in high class office buildings, namely, the proper service of "local" and "express" elevators. The formulas given below are well substantiated, giving economical service conditions as based on existing systems in the larger cities of the U. S., and by which the number of elevators required, the division of service, and their operation may be determined.

(1) $E = A \div 24000$

(2) $f = \frac{n}{2} + 2$

(3) $Te = \left(\frac{25}{s} + \frac{5}{100} \right) n$, and $Tl = \left(\frac{25}{s} + \frac{1}{10} \right) n$

(4) $Me = 2n \div 7\ Te$, and $Ml = 2n \div 7\ Tl$

(5) $Ce = 115n \div 100\ Te$, and $Cl = 115n \div 100\ Tl$.

The notations in the formulas are:

E = number of elevators required.
A = sq. ft. of gross building area served.
f = floor at which express run terminates
n = total number of floors served.
s = speed of elevator, in ft. per minute.
Tl = local round trip time in minutes.
Te = express round trip time in minutes.
Ml = miles traveled per hour by local.
Me = miles traveled per hour by express.
Cl = current consumed per hour by local in kw.-hrs.
Ce = current consumed per hour by express, in kw.-hrs.

TABLE XIX. UNIT-AREA, LOAD AND SPEED COMBINATIONS

Bldg. ht. floors	Car area sq. ft.	Load lbs.	Speed ft. per min.
8–13	25	1700	250–350
14–22	30	2000	350–600
23–30	40	3000	400–600

The figures in Table XIX represent the average load and speed combinations for various heights of buildings, together with the usual area of the elevator car as is consistent with the standard sizes manufactured, and should be used as a basis for selecting the proper unit areas in connection with formula No. 1. The many factors entering into the operation of an elevator would affect the current consumption to a considerable extent, as may be seen by Fig. 48 hereinbefore explained. But formula No. 5 agrees with modern service under average operating conditions.

In order to facilitate the ready understanding of the various formulas given, Table XX, embodying the computations, is presented. The various headings included are numbered in respective order from 1 to 12, so that an explanation of the items considered will not be confusing. Under column 1 is listed the heights of buildings, with the assumed floor areas extending the full height of the structure given in column 2. In column 3 is listed the

actual sq. ft. of car area now provided in many buildings of similar floor space having an adequate service. This is intended as a guide where the considerations in planning the building have included a means of accommodating the standard size elevators most suitable for that building and wherein serious attention has been given to the disposition of the cars. But on the other hand, the values listed may also be used to advantage in proportioning the number of elevators required under any conditions, and where the physical aspect of the building does not allow for an economic disposition of the elevators. Any conservative unit-area best suited to the conditions may then be allotted for each car, and thereby solve for the number of elevators necessary.

TABLE XX. ELEVATOR INSTALLATION DATA

1	2	3	4	5	6	7
Building		Number of elevators required				
Number of floors	Gross area in sq. ft.	Total sq. ft. of car area	Cars at 25 sq. ft.	Cars at 30 sq. ft.	Cars at 40 sq. ft.	By formula No. 1
8	80,000	89	4	..	..	4
10	100,000	111	4	..	..	4
12	120,000	133	5	..	..	5
14	210,000	262	11	9	..	9
16	240,000	300	12	10	..	10
18	270,000	337	14	11	..	11
20	300,000	375	15	13	10	13
25	375,000	577	..	19	15	16
30	800,000	1221	..	40	30	33

	8	9	10	11	12
	Round trip time in minutes				(f) or
Number of floors	Tl at 350 ft. per min.	Tl at 500 ft. per min.	Te at 500 ft. per min.	Te at 600 ft. per min.	Express run. in floors
8	1.3	....	....	....	....
10	1.7	....	....	....	....
12	2.0	....	....	....	....
14	2.4	2.1	....	....	....
16	2.7	2.4	1.6	....	10
18	....	2.7	1.8	....	11
20	....	3.0	2.0	1.8	12
25	....	....	2.5	2.3	15
30	....	....	3.0	2.7	17

It will be noticed that in columns 8 and 9 the time occupied in traversing the height of buildings exceeded eighteen stories is slightly more than would actually prove economical. It might be well therefore to point out that the speeds of local elevators for high buildings might be increased to advantage; but whether the service be local or express, it is not advisable to exceed a speed rate of 600 ft. per min.

In order to rectify this condition, under the speeds considered, the number of express elevators must then be more than half the total system, and a sub-division of express service proper is also necessary.

It is often helpful to be informed as to the size of motor required

for an installation, and the diagram, Fig. 49, may be used for this purpose. For sake of illustration in the use of the diagram, a speed of 400 ft. per min. is assumed, with a combined load of 2,500 lbs. Following the line marked with an arrow from the

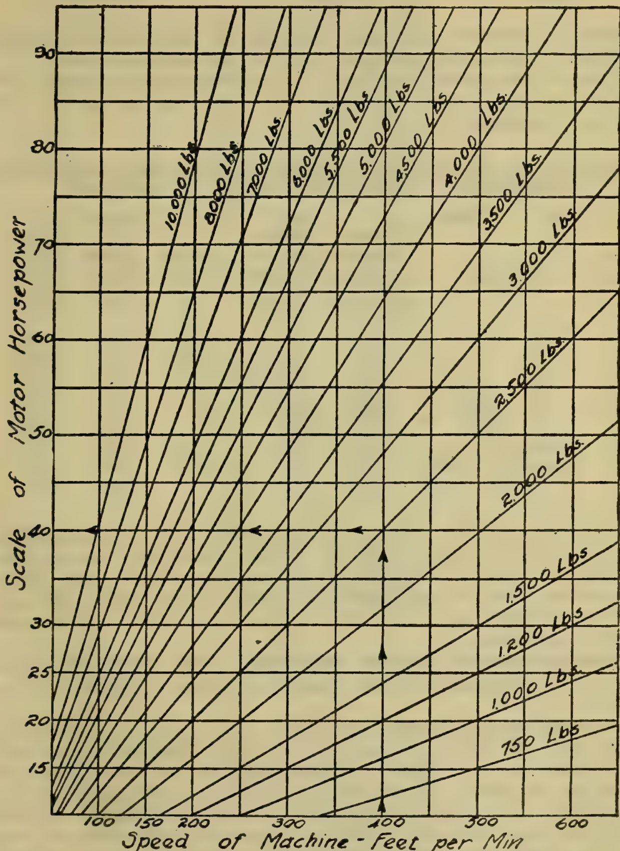


Fig. 49. Motor sizes for electric elevators.

speed of 400 ft. the point of intersection is then at 2,500 lbs. From this point follow the line as indicated to the scale of motor sizes, and the result is above 40 h.p.

Table XXI gives the current consumption of motor sizes

TABLE XXI. CURRENT CONSUMPTION

Motor size	Starting current	Running current
20 h.p.	102 Amp.	74 Amp.
40 h.p.	202 Amp.	148 Amp.
60 h.p.	292 Amp.	213 Amp.

common in elevator practice. The figures are for d.c. motors operating at 230 volts, and are based on the results of tests.

To aid in the selection of well proportioned electric feeders for elevator motors, Table XXII is given. The figures are for 230 volt, d.c. machines.

TABLE XXII. WIRE AND CONDUIT SIZES FOR ELECTRIC ELEVATORS, 2 WIRE, 230 VOLT, D. C. SYSTEMS

Motor h.p.	Wire: Size of each wire	Wire: Under-writers amp. carrying capacity	Maximum run or distance in ft. for 2% drop	Conduit: Trade size for 2 wires, ins.	Conduit: Inside diameter, ins.	Conduit: Outside diameter, ins.
15	No. 3	80	154	1¼	1.38	1.66
20	No. 1	100	174	1½	1.61	1.90
25	No. 0	125	186	1½	1.61	1.90
30	No. 00	150	198	2	2.06	2.37
35	No. 000	175	212	2	2.06	2.37
40	No. 0000	225	226	2	2.06	2.37
45	No. 0000	225	226	2	2.06	2.37
50	300,000 cir. mils.	275	248	2½	2.46	2.87
50	300,000 cir. mils.	275	248	2½	2.46	2.87
60	400,000 cir. mils.	325	272	3	3.06	3.50

Power Consumption of Electric Elevators. C. D. Wesselhoeff is authority for the data in Table XXIII, giving the power consumption of electric elevators at various loads and stops. Type of machine, one to one electric traction. Total weight of car, 3,956 lbs. Overbalance, 1,060 lbs. Capacity, 2,500 lbs. at a speed of 500 ft. per min.

Operating Costs of Electric Elevators. Table XXIV was prepared from a circular of the Cincinnati (Ohio) Gas and Electric Co.

Operating Costs of Electric Elevators. The following is from an article by C. W. Naylor, Power, Feb. 5, 1918. The electric passenger elevator has now been in service for a period long enough to enable the engineer to report intelligently on its cost of operation, maintenance and repair. Hitherto, reports on electric-elevator costs have been in a great measure based on tests made at the time of, or very soon after, installation, and the real cost, such as could be shown only by records of years of operation, has in the main been a matter of conjecture. The repair or maintenance side of the ledger, in which cost records are tabulated, shows a marked increase as the machine becomes older, after making due allowance for the advance in the cost price of repairs, which is now so noticeable.

TABLE XXIII. POWER CONSUMPTION AT VARIOUS LOADS AND STOPS

Stops at floors Nos. Up.	1 and 9.							1, 5, and 9.				
Stops at floors Nos. Down.	9 and 1.							9, 5, and 1.				
Distance	101 ft. 6 in. one way or per trip = 52 trips per car mile.											
Load, lb.	Operator	666	1,060	1,360	2,010	2,360	2,660	Operator	666	1,060	2,010	2,660
K.w.-hr. per car mile	2,345	2.075	1.945	1.87	2.15	2.495	3.22	3.09	2.855	2.52	2.915	3.85

Stops at floors Nos. Up.	1, 3, 5, 7, and 9.				1, 2, 3, 4, 5, 6, 7, 8, and 9.			
Stops at floors Nos. Down.	9, 7, 5, 3, and 1.				9, 8, 7, 6, 5, 4, 3, 2, and 1.			
Distance	101 ft. 6 in. one way or per trip = 52 trips per car mile.							
Load, lb.	Operator	666	1,060	2,010	Operator	666	1,060	2,010
Kw.-hr. per car mile	....	4.91	4.185	3.975	4.25	7.285	6.75	6.7	7.425

TABLE XXIV. COST OF ELECTRIC ELEVATOR OPERATION

(Six months' average)

Freight elevators *			Passenger elevators †		
No.	H.p.	Average monthly cost	No.	H.p.	Average monthly cost
1	10	$11.92	1	15	$39.54
1	10	10.00	2	20½	19.05
5	20	33.01	1	18	65.83
1	5	5.00	2	17½	17.30
1	5	4.00	1	22½	23.57
1	5	5.00	1	15	14.22
1	5	4.00	5	73	59.40
1	5	7.37	2	32	38.16
1	5	4.00	3	38½	34.55
1	5	11.86	2	10½	19.80
1	10	9.50	1	8	9.73
1	10	9.50	1	8	14.87
1	8½	9.49	1	11	18.42
2	25	23.75	1	15	9.15
1	5	3.50	1	15	22.01
1	10	9.50	1	15	4.75
1	5	4.75	2	16½	17.62
1	10	11.30	1	12½	14.66
1	8	7.60	2	12½	12.33
1	20	28.06	2	11	17.74
1	7½	7.12	3	41	37.95
1	5	4.75	1	10	23.49
1	5	4.60	1	16	18.24
1	5	5.25	1	10	19.05
1	7½	7.12	1	10	19.50
..	..	....	1	13	13.30
..	..	....	1	10	18.98
..	..	....	1	26	35.31
30	221½	$241.95	45	523	$658.58

* Average cost per elevator per month, $8. Average cost per month per h.p., $1.09.

† Average cost per elevator per month, $14.64. Average cost per month per h.p., $1.26.

This article is based on the records for 10 years, ended Dec. 31, 1916, for 50 worm-gear, drum-type elevators having a 150- to 230-ft. lift and running in passenger service at a maximum speed, loaded, of 350 ft. per min. The elevators cited are all in one building, operated in a similar manner, doing exactly the same kind of work for equal numbers of hours per day, and cared for by the same set of mechanics, using the same oils, grease, cables, ropes, brushes, etc.

They are all of the overhead drum type, as shown in Fig. 50, overbalanced as to counterweight and equipped with all the standard accessories that go with this make of elevator. They are operated on direct current at about 226 to 230 volts, with magnet control of the usual construction and steel guide rails for cars and counterweights. There are two sets of counterweights, one for the drum and one for the car. All cables are standard, ¾ in. diam., running over idler sheaves and drums of approximately 46 ins. diam. The car-counterweight cables, two in number, pass directly over the vibrating or idler sheave *A*, while the car-hoisting

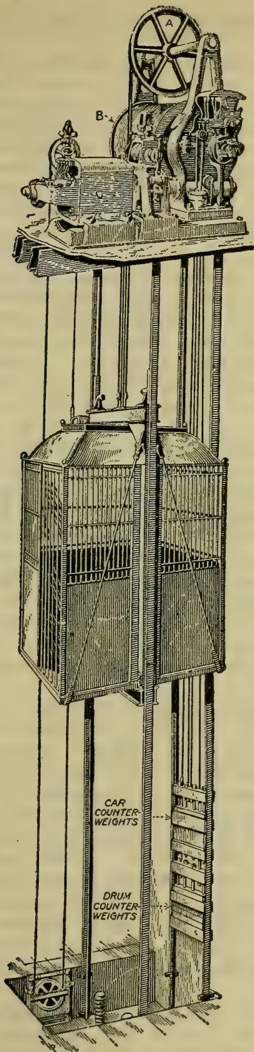


Fig. 50. Overhead type elevator machine.

cables wind on the drum *B* as the drum-counterweight cables unwind, and vice versa.

There are no equalizing or compensating cables or chains. The cars, or cages, of a rather heavy pattern, weigh approximately 4,000 lbs. each, and the double counterweights about 5,000 lbs. The drums are driven by double, or fore-and-aft, bronze worm gears meshing with steel worms on an extension of the armature shaft, with the magnet brake installed on this shaft between the armature and the worm. The armature revolves at 850 r.p.m. when on high speed, and the drums make about 30 revolutions during the same period. Of the cars listed, 5 have a travel, or rise, of 150 ft., 40 have 200 ft. and 5 220 to 230 ft.

In addition to the overhead type of passenger cars, there are 5 machines of the basement type, the driving mechanism being at the lower landing, with traveling idler sheaves over the drum. The lift is about 40 ft. For the various items shown in the table the operating costs are about the same. The extra cable wear is in a measure compensated for by the shorter length, the cables wearing out in 2 or 3 yrs. as against 6 to 10 yrs. for the longer lifts. There are also 11 freight elevators of overhead type, 220 ft. travel, with a somewhat slower speed and smaller motors. These machines cost 10% less for all items shown in the table, except for cables, and 50% less for these. Their speed is 250 ft. per min., and they travel about 6 to 8 miles per day as against 12 to 15 miles each per day for the passenger cars.

The labor shown is for the wages of the maintenance and repair mechanics. Each man cares for 12 cars, oiling, cleaning, adjusting and ordinary repairs. 2 extra men care for the heavy and extraordinary repairs such as installing armatures, greasing guides and putting on cables. The increase from year to year is occasioned by some additional help and wages advanced for the old employees.

The item miscellaneous includes leather for brakes, copper rivets, babbitt, bolts, screws, etc. The armature expense is mostly for rewinding and includes a few field-coil renewals. The repair item includes brushes, controller disks, contact lugs, carbons and such material as would naturally be purchased from the manufacturer of the machine, used mostly in keeping up the controller boards. Oil includes engine oil for bearings and guides and castor or castor-machine oil for the worm cases. Cables include the ¾-in. main cables and the ½-in. wire and ⅝-in. manila rope for the governors.

Each passenger car travels about 13 miles per day, and for the year of 310 days, totals 4,030 miles. Dividing the average annual cost per car by this mileage gives a maintenance cost of $0.0387 per car mile, of which about 75% is for labor and 25% for materials and supplies.

In the same plant are 11 worm-gear one-to-one traction machines having 230 ft. rise in the hatchway, with compensating chains. The cars travel 375 ft. per min., or 14 to 16 miles per day. Maintenance costs at present are about the same as for the old drum types, except for cables, which wear out about twice as

TABLE XXV. MAINTENANCE COSTS OVER 10 YEARS FOR 50 ELECTRIC ELEVATORS *

	1907	1908	1909	1910	1911	1912
Oil	93	93	93	68	68	110
Grease	8	16	16	25	26	34
Repairs	425	1,105	618	465	467	603
Armatures	1,060	1,160	461	1,148	935	540
Cables	....	467	188	323	140	174
Labor	5,000	5,000	5,525	5,525	5,525	6,375
Misc.	110	59	307	238	344	170
Total	6,696	7,900	7,208	7,792	7,505	8,006
Per car	134	158	145	156	150	160

	1913	1914	1915	1916	Total	Average
Oil	110	78	92	52	857	86
Grease	28	29	31	9	222	22
Repairs	119	40	39	96	3,977	398
Armatures	918	580	660	362	7,824	782
Cables	213	316	360	1,012	3,193	319
Labor	6,375	6,450	6,450	7,650	59,875	5,988
Misc.	269	84	270	92	1,943	194
Total	8,032	7,577	7,902	9,273	77,891	7,789
Per car	161	151	158	185	1,558	156

* For simplicity all amounts given to the nearest dollar.

fast as they do on the drum machines. These elevators are now only 3 yrs. old, and it is too early to pass upon their real cost of operation.

There are also 5 basement worm-gear one-to-one traction machines with compensating cables, having 140 ft. lift and a speed of 300 ft. per min. The ropes on these machines wear out very rapidly.

In addition to the foregoing there are 8 one-to-one overhead traction machines having 280 ft. lift, 450 ft. speed and equipped with compensating cables and weights. The cars travel about 20 miles per day each, and the cables are wearing out three times as rapidly as those on the old drum machines. These cars having been in use only 3 years, it is wisdom to defer decision on their operating cost to a later date.

In the plant there are 77 passenger and 14 freight elevators traveling about 1,500 miles and carrying from 150,000 to 325,000 passengers per day. The cost per car-mile for current is practically the same for all types.

Economy of the Electric Motor Drive for Contractor's Hoists. W. H. Easton in Engineering and Contracting, Jan. 21, 1914, compares the costs of hoist operation with coal and electricity as follows:

With a coal hoist in Pittsburg, where a motor was directly substituted for a steam engine, all other factors remaining the same, the following results were obtained:

Cost of coal per month	$ 60
Cost of water	15
Wages of engineer	125
Total	$200

Cost of electric power per month	$ 77
Wages of motor operator	75
Total	$152

Thus the electric hoist showed a saving of $48 per month. But it also proved itself able to handle more coal. With the steam hoist, a bucket containing 42 bushels was lifted every 60 seconds, whereas the electric hoist required only 50 seconds for the trip, because it could be accelerated more rapidly. Hence in a 10-hour day the electric hoist can perform 120 more trips, or handle over 5,000 bushels more than the steam hoist.

CHAPTER XIX

HEATING, COOKING, VENTILATING, REFRIGERATING AND ICE MAKING

Cost of Heating Buildings as given by George W. Martin in a paper before the American Society of Heating and Ventilating Engineers is printed in Power, Feb. 15, 1916. In the Tweedy formula, tons of coal per year $= \frac{W}{4.5} + 2G$, where W is the net wall surface and G is the glass surface in units of 100 sq. ft.

Mr. Boyden's formula is somewhat complicated, but in the writer's opinion it has the advantage that it takes into consideration a difference in the operating conditions in the different buildings. Experience is necessary in the use of this formula, however, as serious errors are likely to affect the variable to such an extent that the calculated result will be far from correct. The formula follows:

$$\text{Tons of coal per year} = \frac{\dfrac{V \times a}{60} + (C_1 \times G) + (C_2 \times W)}{C_3 \times (130 - T)} \times L \times d \times h \times \frac{34}{e \times 2{,}000}$$

in which

V = Gross volume of the building, including basement, if heated;
G = Sq. ft. of glass surface, 10% being added for north and west exposures;
W = Sq. ft. of wall surface, 10% being added for north and west exposures;
a = Average air changes per hour during heating period;
C_1 = Constant for glass — 1 for single glass.
C_2 = Constant for wall — usually 0.2 for brick and 0.3 for stone;
C_3 = Constant for local conditions — 5.4 for Boston, 5.7 for New York;
T = Factor dependent upon the relation the heating plant bears to the premises heated;
L = Factor for portion of building not heated or for building heated to 70 deg. F.;
e = Average evaporation in lb. of steam per lb. of coal;
d = Number of heating days during season;
h = Average number of hrs. of heating per day.

Under normal operating conditions, when steam is on the heating system for from 3,200 to 3,500 hrs. during the heating season of

seven months, the two formulas agree fairly well with the actual results, as shown in the case of three buildings, as follows:

	Building		
	No. 1	No. 2	No. 3
Actual coal, net tons	655	486	1,572
Tweedy formula	625	380	1,500
Boyden formula	650	469	1,545

While the three amounts agree closely in the case of buildings Nos. 1 and 3, for building No. 2 the result by the Tweedy formula is much below the actual, probably owing to the fact that much heat was wasted through leaky windows, increasing the amount of air change per hr.

Among those in charge of building operation for the United States Government, the practice is followed of assuming the condensation of 500 lbs. of steam per sq. ft. of radiating surface per season. The writer believes this to be a safe figure, as in the case of the three buildings cited, the condensation approximated 400 lbs., 430 lbs., and 420 lbs., per sq. ft. per season respectively, assuming an evaporation of 7 lb. in each case.

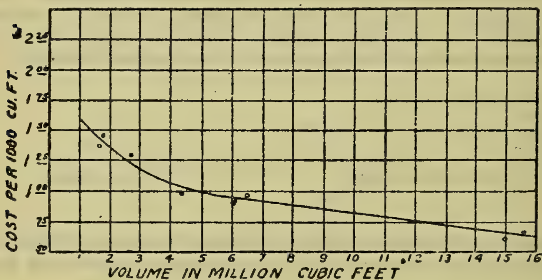


Fig. 1. Cost of operation of heating system per thousand cu. ft. of gross volume.

The writer's method of estimating the coal requirements for heating a building is to employ the Tweedy formula and check with the Boyden formula and the Government method. A comparison of the results with the known requirements of a similar building completes the process.

While the amount of coal required depends largely on the amount of exposed wall and glass surface, yet it has been found that the total cost of operation bears a fairly well-defined relation to the volume of the building.

From the results obtained over the last 5 years a curve shown in Fig. 1 has been plotted showing the cost of operation in dollars per thousand cubic feet of gross volume. The costs include fuel, labor, ash removal, make-up water, supplies and repairs. The coal used was No. 3 Buckwheat at $2.50 per ton. This curve is not to

be used as an absolute method of determining heating costs, but is rather intended as an approximation to give the consulting engineer some idea of the operating cost of a system which he designs. The buildings from which the results were obtained are all largely on direct systems, the buildings of 6,500,000 and 15,000,000 cubic feet having vacuum returns.

Fig. 2 shows the cost of steam generation for various amounts of steam generated, in a certain case where the boiler plant is located 750 ft. distant from the building heated. The customer is billed on

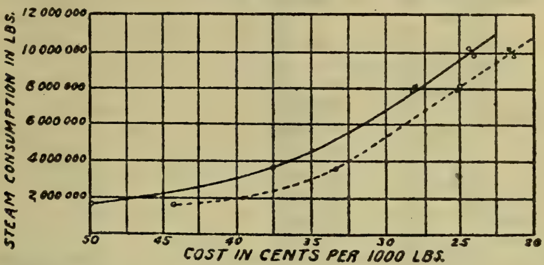


Fig. 2. Cost of steam generation for various amounts of steam generated.

the basis of the readings of a meter in the building. The full line in Fig. 2 shows the cost based on meter readings in the power plant. The difference represents the loss due to condensation in the line. The plant is operated only when heating is required and is equipped with three boilers each operating at 100 lbs. pressure. The boiler-feed water comes from a heater at a temperature well above 200 deg. F. Other operating data follow:

Coal: No. 3 Buckwheat ($2.50 per ton delivered) burned with balanced draft.

Number of days	227	Tons of coal, gross	3337
Aver. outside temp.	40.9 deg.	Rate of evaporation	6.34
Steam generated, lbs.	47,401,000		

Cost per 1,000 lb. of steam:

Coal	$0.193	Elec. current, blower	$0.006
Labor	.063	Supplies	.006
Ash removal	.008	Repairs and misc.	.002
Make-up water	.001	Fixed charges on invt.	.033

Total cost per 1,000 lb. of steam $0.312

Coal Required per Season for Steam and Hot Water Heating. Fig. 3, taken from the Heating and Ventilation Magazine, Sept., 1916, readily shows the approximate amount of coal required per season for steam and hot water heating.

To use chart, select point on left-hand vertical line indicating square feet of radiation and piping. Connect this point with point on right-hand vertical line indicating duration of heating season. The point where the line crosses the middle vertical line indicates

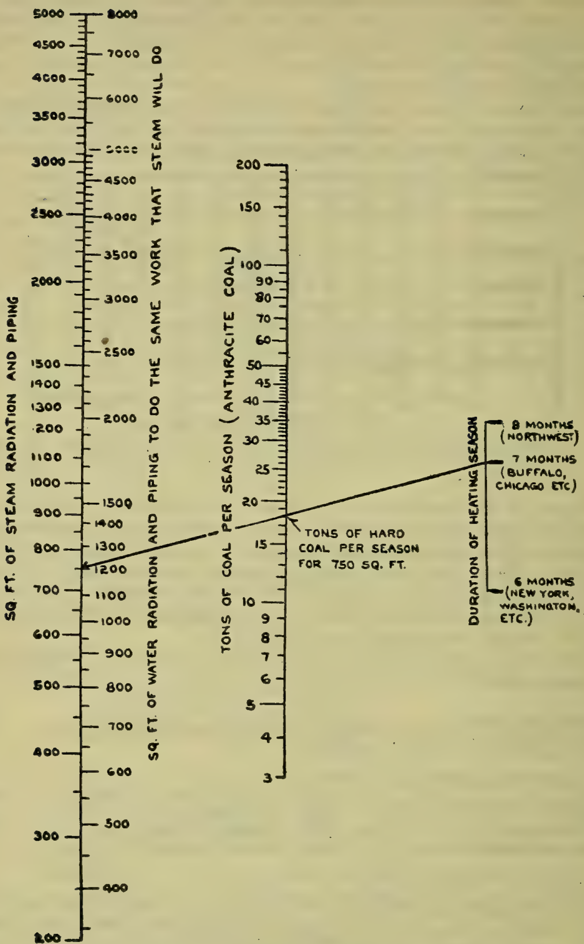


Fig. 3. Chart for figuring amount of coal required per season for steam and hot water heating.

the approximate amount in tons of anthracite coal required per season.

Figuring the Coal Consumption for Apartment and Office Buildings. H. M. Hart, in Metal Worker, Plumber and Steam Fitter, April 14, 1916.

Apartment House Heating. To find the theoretical coal consumption, assume a Chicago apartment building which is heated by steam to 70 deg. The average outside temperature for the heating season of seven months, from Oct. 1 to April 31, is approximately 35 deg., and the minimum is 10 deg. below zero.

The average difference in temperature between the outside and inside is 35 to 70 = 35 deg. and the maximum difference is —10 to 70 = 80 deg. Therefore, to maintain an average temperature in the building of 70 deg. the radiators would have to be hot 35/80ths of the time, and this represents the average steam demand.

Then during the heating season of seven months, or 5040 hrs., the radiators would be hot 35/80ths of 5040 = 2205 hrs. The amount of heat given off by the average standard height steam radiator in a room temperature of 70 deg. is approximately 225 B.t.u. per square foot of surface per hour. On a basis of 100 sq. ft. of radiation, the heat given off per heating season would be as follows: $100 \times 225 \times 2205 = 49{,}612{,}500$ B.t.u.

It has been found by numerous tests that a good grade of semi-bituminous or Pocahontas coal in the average heating boiler will give off about 8000 available B.t.u. per pound of coal. Therefore, the theoretical coal consumption per 100 sq. ft. of radiation surface per heating season would be $\frac{49{,}612{,}500}{8000} = 6201$, or 3.1 tons.

To check this with operating conditions, figures of actual fuel consumption in seven modern apartment buildings were obtained. These are heated by single-pipe steam systems using Pocahontas coal in firebox of return tubular boilers, with the following results:

Bldg. No.	Sq. ft. radiation	Tons of coal per season: Total used	Tons of coal per season: Per 100 sq. ft. radiation
1	3,435	219	6.40
2	6,000	334	5.56
3	900	36	4.00
4	7,076	465	6.60
5	3,900	190	4.88
6	7,341	215	2.93
7	2,559	170	3.23

Buildings Nos. 1, 2, 4 and 5 were erected by speculative builders and consequently not much attention was given to the efficiency of the heating systems. The result is that the present owners are burning about twice the amount of fuel that they should.

Buildings 3, 6 and 7 were erected as permanent investments and the heating system in each building was installed by a reputable heating contractor. The systems were properly designed and are ample in capacity. The owners might be well satisfied with their investment, although they undoubtedly paid more per square foot

of radiation for their heating systems than did the owners of buildings 1, 2, 4 and 5.

The yearly loss to the owners of these four buildings is as follows:

$$\text{Bldg. No. 1} \quad (6.4 - 3.1) \times \frac{3435}{100} \times \$4.50 = \$510.10$$

$$\text{Bldg. No. 2} \quad (5.56 - 3.1) \times \frac{6000}{100} \times \$4.50 = \$664.20$$

$$\text{Bldg. No. 4} \quad (6.6 - 3.1) \times \frac{7076}{100} \times \$4.50 = \$1{,}114{,}47$$

$$\text{Bldg. No. 5} \quad (4.88 - 3.1) \times \frac{7341}{100} \times \$4.50 = \$588.00$$

A first-class single-pipe steam heating system can be installed for about $1 per square foot of surface, but the builders probably paid no more than 75 cents per square foot for these four jobs. Therefore, the saving on cost of installation was about as follows:

Building No. 1	3435 × $0.25 = $ 858.75
Building No. 2	6000 × 0.25 = 1,500.00
Building No. 4	7076 × 0.25 = 1,769.00
Building No. 5	7341 × 0.25 = 1,835.00

This appears to be a very extravagant saving. The investment of this additional amount in the heating systems would have netted the owner from 32 per cent. to 63 per cent. profit.

The above simply illustrates how true that old saying is, that one gets about what one pays for no matter how rigid the specifications or the contract may be.

The Office Building Problem. A slightly different problem is presented in considering the cost of operation of the heating and mechanical plants in office buildings. The following interesting comparison is drawn between two modern office buildings — one equipped with a heating apparatus only and the other equipped with its own power plant.

In the first building, which has a simple heating apparatus of the vacuum type, temperature control, low pressure boilers and smokeless furnaces, the theoretical fuel consumption is as follows:

Direct radiation, 60,850 sq. ft.

The average outside temperature for the seven heating months of 1911 and 1912 was 33.6 deg.; therefore, the theoretical number of hours that radiators would be turned on would be $70 - 33.6 = \frac{36.4}{80}$ or 45.5 per cent. of 310 days × 24 hrs., which would be 2293 hrs. Therefore, the steam required for heating would be

$$\frac{60{,}850 \times 225 \times 2293}{961} = 32{,}668{,}091$$

pounds. To this should be added the loss through the covered piping, estimated at 3 per cent. of the total, which would make the total loss by radiation, 33,648,133 lbs.

For ventilation there are the following units: 1 unit delivering 32,420 c.f.m. at an average rise of 26.4 deg. for 20 hrs. per day; 1 unit delivering 18,400 c.f.m. at an average rise of 28.4 deg. for 20 hrs. per day; 1 unit delivering 33,860 c.f.m. at an average rise of 51.4 deg. for 10 hrs. per day; 1 unit delivering 19,500 c.f.m. at an average rise of 76.4 deg. for 10 hrs. per day.

Cost of Generating Steam. The steam required for above service would be as follows:

$$\frac{\overset{\text{R.}}{32{,}420} \times \overset{\text{M.}}{26.4} \times 60 \times \overset{\text{Hrs.}}{20} \times \overset{\text{Da.}}{180}}{55 \times 961} = 3{,}497{,}717 \text{ lb. of steam}$$

$$\frac{18{,}400 \times 26.4 \times 60 \times 20 \times 180}{55 \times 961} = 2{,}135{,}521 \text{ lb. of steam}$$

$$\frac{33.860 \times 51.4 \times 60 \times 10 \times 180}{55 \times 961} = 3{,}556{,}212 \text{ lb. of steam}$$

$$\frac{19{,}500 \times 76.4 \times 60 \times 10 \times 180}{55 \times 961} = 3{,}044{,}147 \text{ lb. of steam}$$

making a total of 12,233,597 lbs. of steam for ventilation, which, added to that required for heating, makes a total of 45,881,730 lbs. of steam, which, when burning screenings and evaporating 6 lbs. of water per pound of coal, would take $45{,}881{,}730 \div (6 \times 2000) =$ 3823 tons.

The actual fuel consumption per month was as shown in the accompanying table.

	Theoretical tons	Actual tons	Outside temperature degrees	Average wind velocity, miles
October	248	301	53.3	12.8
November	542	573	35.4	16.9
December	547	468	35.0	14.4
January	783	913	11.9	14.2
February	759	656	21.8	14.4
March	640	661	28.8	13.5
April	338	286	48.8	16.5

It will be noticed from this table that during the months of November and December the temperature was about the same, but the wind velocity decreased about 15 per cent. and the fuel consumption about 18 per cent. The difference between the months of April and October, of course, is not consistent, but as the engineer had no means of weighing the coal as it was put into the boilers the figures given per month might not be absolutely correct.

The actual cost of operation of this heating plant is as follows:

Coal, 3,858 tons at $2.37	$ 9,143.46
Removing ashes	554.00
Oil, waste and packing	160.00
Repairs	100.00
Labor	4,500.00
Electric current for vacuum and boiler feed pumps	429.00
Water, approximately	200.00
Interest and depreciation, 10 per cent	2,892.00
	$17,978.46

Then the actual cost of producing steam is $\frac{1000 \times \$17{,}978.46}{3858 \times 6 \times 2000} = 38.8$ cts. per 1000 lbs., and if the fuel for water heating were added in, there would be an additional expense of $2,883 for coal and $174 for removing ashes, making the total expense per year $21,035.46. This would bring the cost of steam per 1000 lbs. down to

$$\frac{1000 \times 21{,}035.46}{5074 \times 6 \times 2000} = 34.6 \text{ cts.}$$

In another building, almost a duplicate, having its own electric generating plant and hydraulic elevators, the heating load would be about as follows: 68,000 sq. ft. direct radiation, at

$$\frac{68{,}000 \times 225 \times 2293}{961} = 36{,}506{,}660 \text{ lb. of steam}$$

The pipes were covered with molded asbestos, so loss through same may be estimated at 4 per cent., which would bring this load up to 37,946,926 lbs.

For heating water the load is about the same as in the previous building, which required 14,600,000 lbs. of steam, making a total of 52,546,926 lbs.

The cost of operation is as follows:

6,275 tons No. 4 washed nut at $3.00	$18,825.00
Removing ashes	890.00
Oil, waste, and packing	470.00
Water	2,407.00
Lamp renewals	486.00
Labor	9,320.00
Interest and depreciation, 10 per cent.	7,000.00
	$39,398.00

To obtain cost of steam for heating, the following deductions must be made:

For 644,742 kw. generated:			
Fuel (at 49 lb. steam per kw.)	$6,551		
Water	249		
Lamps	486		
Ashes	310		
Oil, waste and packing	100		
Labor	1,884		
Interest and depreciation	3,000		
	$12,580	$12,580	
For elevators:			
Coal	$7,712		
Water	257		
Ashes	364		
Oil, waste, etc.	300		
Labor	2,700		
Interest, etc.	1,000	$12,333	$24,913
			$14,485

Then $14,485 is the additional cost for heating.

If this were taken at the same cost rate as the previous building, the cost of heating would be 52,566,926 lbs. of steam at 34.4 cts. per 1000 lbs., or \$18,083. Therefore, the saving on cost for heating is \$18,083 — \$14,485 = \$3,598.

However, this does not represent the actual saving showing the operation of this plant. The saving would be as follows:

Cost of heating without plant	\$18,083
Revenue for kw. sold	25,855
Revenue for kw. for public lighting	9,928
Cost of elevator service	12,333
	\$66,199
Less cost of operation	39,398
Annual saving	\$26,801

Figuring Ventilation. The cost of operation of a ventilating apparatus varies greatly with the installation; but under normal conditions where the system is designed to deliver air at a temperature of 75 deg., taking outside air at an average of 35 deg., the steam required will be

$$\frac{1000 \times 40}{55 \times 961} = 0.75 \text{ lb.}$$

per 1000 cu. ft. The power will be

$$\frac{\text{C.F.M.} \times 9 \times \text{pressure in oz.}}{33{,}000 \times 50}$$

which for 1 oz. pres. = 0.5454 hp. per 1000 cu. ft.

The horsepower required varies directly with the pressure.

For estimating the volume of air required the following formula is found to be quite accurate:

H = total B.t.u to be supplied per hour.
D = difference in temperature between room and incoming air.
F = cubic feet of air per pound at the temperature leaving coils.
V = cubic feet per minute required.

$$V = \frac{F\,H}{0.2375\,D \times 60} \text{ or } \frac{F\,H}{14.25\,D}$$

Cost of Heating and Power Plant Apparatus. The following figures are given by W. J. Downing in Power, Nov. 18, 1913. Prices are based on actual installations, most of them in the New England States, and allowance should be made for other localities, based on the difference in cost of labor and material.

Radiation. Radiation will be classified under five headings:

1. Cast-iron direct radiators cost 19 to 27 cts. per sq. ft. of surface, depending on the height of the radiator. The labor cost will be nearly the same for casting and finishing a section containing 1 sq. ft. of surface as for a section containing 5 sq. ft.

2. Cast-iron indirect radiators of the pin type for gravity work cost 16 to 18 cts. per sq. ft.

3. Cast-iron radiators for fan systems cost 25 cts. per sq. ft.

4. Pipe coils for direct radiation cost 30 cts. per sq. ft.

5. Pipe heaters consisting of 1 in. pipes with cast-iron bases for fan systems cost 45 to 50 cts. per sq. ft. of surface. For cast-iron bases with a damper for direct indirect radiators add $1.25 for each 10 in. length of base.

The labor cost for installing direct radiators on a one-pipe system can be obtained by allowing one day's time for a steam fitter and his helper for each radiator. This covers the time required to run the vertical risers and connect and set the radiators. It does not include the time required to place the horizontal mains in the basement and connect up the boilers. This item will be covered under another heading. For a two-pipe system allow 1.5 days' time for a fitter and helper per radiator.

Indirect radiators for gravity and fan-blast systems cost about 0.5 ct. per lb. for the former and 1 ct. per lb. for the latter for erection together with the labor cost of a fitter and helper for one day for each four connections made to the heater sections.

Allow 2.5 to 3 cts. per sq. ft. of surface of pipes and radiators for bronzing.

Automatic air valves cost 75 cts. to $1 each in place.

For temporary setting of direct radiators used to furnish heat in the building while under construction, allow $2.25 for each radiator.

Figures based on a large number of installations show that an allowance of $50 per thermostat should be made for automatic control. This includes the air piping, compressor dampers and thermostats, set in place and connected.

Boilers and Auxiliaries. Small cast-iron fire-pot boilers for house heating cost $30 to $35 per sq. ft. of grate area.

Cast-iron sectional boilers for house and public-building heating cost $21 to $25 per sq. ft. of grate area.

Horizontal fire-tube boilers set in place complete with trimmings ready for steam and water connections cost $12 per h.p.

The Manning type of vertical boiler for power-plant work will cost $10 per h.p. erected.

Water-tube boilers set in place with trimmings cost $14 to $16 per h.p.

Internally fired boilers of the Morrison type cost $16 to $18 per h.p., including trimmings.

Dutch or extended ovens are often used in power plants for burning a low grade of fuel, or utilizing the waste material from manufactured products. These ovens will cost $250 for a 300 h.p. unit.

Superheaters cost $2.25 to $3 per h.p., depending on the size and type.

Special boiler settings designed to economize heat, similar to the Smith setting cost about $150 per boiler.

All of the above prices are based on boilers with plain grates. Shaking grates should be figured at from $5 to $6 per sq. ft. of surface.

Feed-water heaters of the closed type cost from 75 cts. to $1 per h.p., depending on the size of the unit. Feed-water heaters and

purifiers of the open type cost $2.20 per h.p. for a 100 h.p. unit and $1 per h.p. for a 1000 h.p. unit. Intermediate sizes cost a proportional amount.

A good damper regulator for controlling the draft in boilers can be obtained for $50.

Boiler-feed pumps cost 50 cts. per h.p. capacity of units of 150 to 200 h.p.

Blowoff and return tanks suitable for 100 lbs. pressure cost about 8 cts. per lb. in weight.

Copper hot-water tanks good for 100 lbs. pressure complete with steam coil cost about $1 per gal. capacity. Add $50 if the tank has automatic control.

Steam traps take a discount of 40% from list prices.

Pipe Fittings and Valves. While there are several large manufacturers of these products it is usually safe to figure the following discounts: Steam pipe, 75%; valves, 50 to 60%; cast-iron fittings, 70%; spiral-riveted pipe, 70%.

An accurate list should be made of the actual material required for any particular installation, as there are too many variables to use a unit price per h.p. capacity of the plant. The labor cost will average $1.50 per h.p. for connecting the boilers and installing the basement mains in plants of 200 to 400 h.p.

The special valves necessary for a first-class vacuum system cost $6 to $8 per radiator. Another method of figuring vacuum systems is to allow 10 cts. per sq. ft. of radiation for the special apparatus required.

Covering. An asbestos covering 4 ins. thick for boilers and heaters will cost in place 50 to 60 cts. per sq. ft. of surface. Air-cell covering 1 in. thick will cost 22 cts. per sq. ft. Eighty-five per cent. magnesia 1 in. thick will cost 30 cts. per sq. ft. These prices include the labor required to apply and are useful in calculating the cost of covering heating ducts and smoke flues.

Steam-pipe covering made of 85% magnesia will cost one-half of the list price, including the labor of applying. If desired the discounts applying to the various types of covering can be obtained and the labor cost based on the fact that one man will cover 100 ft. of straight pipe per day up to 4 in. diameter or will cover 40 fittings per day up to 4 in. size. The above amounts will be more for larger sizes due to the increased labor of handling.

Ventilating Apparatus. Centrifugal steel-plate fans for ordinary systems in which the total pressure does not exceed .75 oz. will cost $10 to $13 per 1000 cu. ft. of air per min. capacity, depending on the size.

Direct-current motors for driving fans will cost $18 to $25 per h.p. Regulating rheostats cost 60% of the list prices.

High-pressure engines for fan driving cost $10 to $16 per h.p. Low-pressure engines for fan driving cost $18 to $22 per h.p.

Air washers are usually based on a velocity of 500 ft. per min. and on that basis cost $18 to $26 per 1000 cu. ft. of air per min. capacity. Erection of fans, motors and air washers will cost about 1 ct. per lb. in weight.

Galvanized-Iron and Steel-Plate Work. Piping arrangements employing galvanized-iron distributing ducts cost about 15 cts. per lb. in place. The ratio of weight of iron to the cubic contents of the building varies widely with different types of building. In factory work where heating is the primary object the galvanized-iron ducts for an overhead system will average 1 lb. of iron to 100 to 125 cu. ft. of contents. In buildings where ventilation is the main object no standard values can be given as the amount of metal will depend on the standard of ventilation maintained. In each case the actual weight of metal must be calculated from the plans.

Steel-plate work for smoke flues costs from 6 to 8 cts. per lb.

Registers and Screens. Cast-iron registers for floors and side walls cost one-fourth the list price. Bronze registers cost one-half the list price. Plain wire screens with angle- or channel-iron borders cost 15 to 25 cts. per sq. ft. Allow 3 cts. per sq. ft. for bronzing.

Filter screens of cheese cloth for removing dust from the air are based on a velocity of 30 to 50 ft. per min. through the net area. Their cost will be from 50 to 70 cts. per sq. ft., depending on the quality of material. Mushroom ventilators cost 65 to 75 cts. each.

Foundations. Allow 75 cts. per cu. yd. for excavation in ordinary soil and $4 per cu. yd. for rock. Brick foundation walls cost 40 to 50 cts. per cu. ft. in place. Concrete foundations cost $6 to $7 per cu. yd. for the concrete and 15 cts. per sq. ft. of surface for the forms. Water-proofing will cost 40 cts. per sq. ft.

Sprinkler Systems. Sprinkler systems cost from $3 to $3.25 per head, including pipe, sprinkler heads and erection. Hose racks for fire protection in public buildings cost $50 each, including piping and erection.

Gas Piping. In fireproof buildings gas-pipe systems cost $5 to $6 per outlet for labor and material. For residences of the usual frame construction allow $2.50 to $3 per outlet.

Unit Costs. While the conditions of various installations make it impossible to give a unit price for a system that will apply in all cases the average of a large number of jobs shows some interesting results. The average cost of a heating system for dwelling houses, using direct-steam radiation is 80 cts. per sq. ft. of radiation. For office and factory work allow $1 per sq. ft. of radiation. For hot-water direct radiation allow $1.25 per sq. ft. for radiation. To these prices should be added that of the boilers to obtain the cost of the entire system.

Although the size of direct-steam radiators varies over a wide range the cost of complete systems, exclusive of boilers, averages $37 per radiator.

All prices stated in this article are the costs to the contractor. An allowance for contractors' profit should be added to the total cost of the system. Profit is usually figured as a percentage of the total cost and will vary from 10 to 15%. It will be noticed that the prices stated above give a considerable range and the question may arise as to the exact value to be used. It may be helpful to note that in any case a price should be selected depending on the

size of the apparatus. For instance, a boiler with 5 sq. ft. of grate area will cost more per sq. ft. than one with 20 sq. ft. By paying attention to the relative size of the unit in question a fair estimate can be made of the cost from the values given.

Mr. Downing's Costs are criticized by A. Robertson, writing from Syracuse, N. Y., to Power, Dec. 16, 1913, as follows. "Under the heading 'Radiation,' pipe-coil heaters for fan systems are estimated at 45 to 50 cts. per sq. ft. of surface. In my experience this should be from 24 to 45 cts. per sq. ft. of surface. This price includes the complete casing and fan connections, the low price being for coils about 7 by 10 ft. and the higher prices of coils down to 3 by 6 ft. Now the designer using Mr. Downing's figures would be justified in using cast-iron heaters exclusively at 25 cts per ft., although as a matter of fact under certain conditions pipe coils are a better proposition.

"Shaking grates instead of costing $5 to $6 per sq. ft. of surface, can be installed for from $3.75 to $4.75 per sq. ft. Open feed-water heaters, good for 10-lb. pressure, complete with oil separator and grease trap, can be bought for about $1 per h.p. as low as the 400 h.p. size, and for 75 cts. per h.p. in the 1000 h.p. size.

"Under the heading 'Ventilating Apparatus,' steel-plate fans are estimated at $10 to $13 per 100 cu. ft. at .75 oz. pressure. This again is far too liberal, $7 to $10 being quite safe.

"Galvanized-iron work is estimated at 15 cts. per lb., which is excessive for average factory work, as 10 cts. per lb. in place will cover a first-class job where local help can be used. Only recently we let a 5-ton job at about 6 cts. per lb., but we realize that this is an exceptionally low figure."

Comparative Cost of Heat When Generated by Coal, Gas and Electricity. H. O. Swoboda in Electric Journal, July, 1913, says:

Coal. Develops at an average a heat of 12,000 B.t.u. per lb. The efficiency of coal burning heating apparatus averages about 10%. Effective heat obtained from 1 lb. of coal = 1,200 B.t.u., from 1 short ton of coal = 2,400,000 B.t.u.

TABLE I. PRICES AT WHICH ELECTRICITY WOULD HAVE TO BE SOLD, TO COMPETE WITH COAL AND GAS, IF THERE WERE NO OTHER ADVANTAGE IN USING ELECTRICALLY GENERATED HEAT

Coal — Electricity		Gas — Electricity	
Coal per ton	Cts. per kw.-hr.	Gas per 1000 cu. ft.	Cts. per kw.-hr.
$1.50	0.17	$0.10	0.2
2.00	0.23	0.20	0.4
2.50	0.28	0.30	0.6
3.00	0.34	0.40	0.8
3.50	0.39	0.50	1.0
4.00	0.45	0.60	1.2
4.50	0.51	0.70	1.4
5.00	0.57	0.80	1.6
5.50	0.62	0.90	1.8
6.00	0.68	1.00	2.0
		1.25	2.5
		1.50	3.1
		1.75	3.6

Gas. Develops at an average a heat of 660 B.t.u. per cu. ft. The efficiency of gas burning heating apparatus averages about 20%. Effective heat obtained from 1 cu. ft. of gas = 132 B.t.u.; from 1,000 cu. ft. gas = 132,000 B.t.u.

Electricity. Develops a heat of 3,413 B.t.u. per kw.-hr. The efficiency of electrically heated apparatus averages about 80%. Effective heat obtained from 1 kw.-hr. = 2,730 B.t.u.

Based on these figures, the same amount of useful or effective heat is generated by 1 kw.-hr. or 20 cu. ft. of gas or 2.25 lbs. of coal.

Operating Costs of Steam and Furnace Heating Plants. Figures by R. O. Stoops (Joliet, Ill.), in the Heating and Ventilating Magazine, Jan., 1916, show that taking three modern steam plants and a like number of furnace blast systems, the comparison favors the furnace blast plants. In both cases the humidity control is taken care of. The essential difference is that in the case of the furnace system, the moisture is introduced into the hot air and the mixed product is conducted throughout the building. In the case of the steam plant, the air to be heated, is drawn through coils, entailing more power and incidentally more coal, at $2.67 per ton.

The report shows that the board installed the new type of plant, more than a year ago, with heat regulation and humidity control, and that the plant has now been in operation for a year, making comparisons possible.

Furnace Blast Heating Cost. Moran Street, power and fuel per 1,000 cu. ft., $1,563; Broadway, $1,836; Woodland, $1,868. Average cost, $1,755.

Steam Blasts Heating Cost. Sheridan school, per 1,000 cu. ft., $2,343; Eliza Kelly, $1,733; Henderson, $3,266. Average cost per 1,000 cu. ft., $2,447.

The report continues: "This shows that the best steam plant costs only $0.135 less to operate than the poorest furnace plant. Local conditions show that this furnace plant (Woodland school) is not doing its best. The above shows that steam costs 39.5% more to operate than furnace."

Interest centers in the report in that Plainfield and Aurora have adopted the Joliet system, which, when first installed in Joliet, was untried in this section.

Cost of Steam Heating Plants. Sheridan, $5,700; Henderson, $5,560; Eliza Kelly, $6,565. Average per school, $5,941. This does not include all the items of installation.

Cost of Furnace Blast Heating Plants. Woodland, Moran and Broadway, $14,725, including heat regulation and humidity control. Average per school, $4,925. When this contract was let the job was lumped to one concern.

Cost of Installing Underground Steam Mains. The following in Engineering Record, Sept. 14, 1912, by Donald M. Belcher, gives the construction and installing costs of heat-insulated underground mains of the Wilkes-Barre (Pa) district heating system.

The new underground installation comprised the construction of 10,791 ft. of mains, varying in size from 6 to 24 ins.; 9982 ft. of

this replaced old mains and 809 ft. consisted of mains into new territory.

Prevention of Heat Loss. The installation, employed to protect the steam mains and prevent loss of heat, was the type which has given the best results, and is now in general use all over the country in district steam heating systems. Tests have shown that the loss from condensation in such lines amounts to less than 5% of the season's steam output.

In this construction only the best quality of strictly wrought-iron line pipe was used and all joints, not adjacent to special fittings,

Fig. 4. Cross section of steam mains.

were made with heavy long pattern couplings. The iron pipe was wrapped with a double spiral winding of asbestos paper, secured in position with copper wire. The pipe thus covered was encased in wood stave casing, the inside diameter of which was from 2 to 3 ins. greater than the outside diameter of the covered iron pipe, thus leaving an annular air space of about 1 in. between the pipe and the casing. Guides and rollers, spaced about 8 ft. apart, center the pipe in the casing and provide for the movement of the pipe in expansion and contraction. The wood casing was made from thoroughly kiln-dried white pine lumber, cut into radial staves, each stave having a tongue and groove running lengthwise. The staves were firmly banded with .1875-in. galvanized steel wire, spirally wound under heavy tension and embedded into the wood. The casing was coated with asphaltum-pitch.

TABLE II. COST OF MAINS TO WILKES-BARRE, PA., COMPANY

Size, ins.	Pavement	Length, ft.	Per lin. ft.
6	Brick	294	$6.03
6	Asphalt	1,585	6.35
8	Asphalt	489	8.01
9	Asphalt	361	9.28
10	Brick	1,053	9.19
10	Asphalt	851	9.36
12	Asphalt	585	11.75
14	Asphalt	2,109	12.33
16	Asphalt	2,607	16.35
20	Brick	552	22.89
24	Brick	275	28.39

18 & 24 brick in station

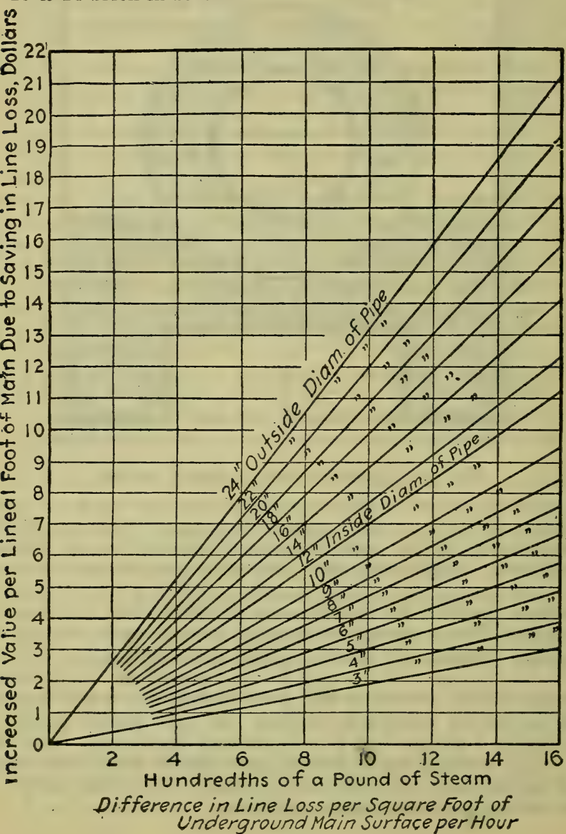


Fig. 5. Value of efficient insulation.

The costs given in Table II were subdivided as follows:

Length of main, ft.	10,761
Repaving	$16,789.51
Trenching	8,406.74
Laying pipe	108,061.92
Incidentals	402.87
Total	$133,661.04
Reconnecting house services	3,067.27
Engineering 1.17%	1,600.64
Total cost of work	$138,328.95

Cost of Underground Steam Heat Mains. Table III gives the cost of steam heat mains exclusive of paving, per 100 ft. of main. These are estimated costs based upon the experience of a large central station on the Pacific Coast.

Efficiency of Underground Steam Mains. (Power, June 17, 1913.) In a paper read before the annual meeting of the Engineering Society of the American District Steam Co., Byron T. Gifford defined the efficiency of a pipe covering as the percentage of heat saved by using the covering. For example, 90% efficiency would mean that the covering saved 90% of the heat lost by the bare pipe. The line loss in underground steam mains varies from .04 lb. or less of steam per sq. ft. of pipe surface per hr. in the most efficient construction to 0.14 lb. or more per sq. ft. of surface with insulation of inferior quality.

Saving in Coal Due to Pipe Covering. In Domestic Engineering,

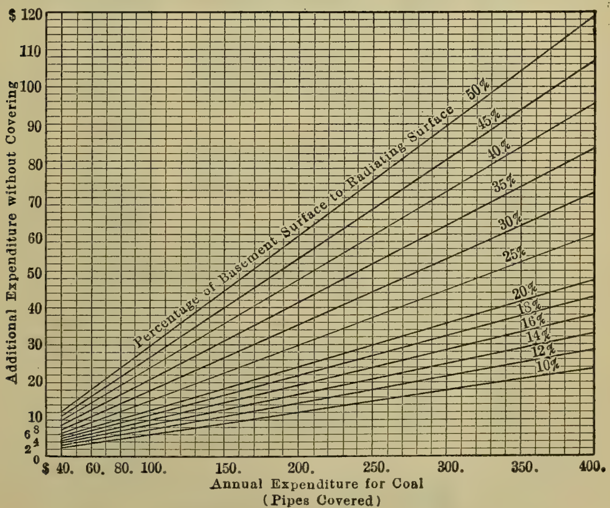


Fig. 6. Annual expenditure for covered pipes.

TABLE III. COST OF STEAM HEAT MAINS — PER 100 FT. EXCLUSIVE OF PAVING

Size of pipe, ins.	Size of trench, ft.	Cost of Material: Wrought iron pipe	Fir casing, wire wound	Duplex covering	Guides at 8 ft. centers	Gravel in place	4-in. drain tile in place	Hauling: pipe casing, covering, guides, etc.	Excavation and back fill at $1.50 per cu. yd.	Labor installing: pipe casing, covering and guides	Total
2½	2.25 by 6.54	$20.87	$95.83	$12.00	$0.45	$3.00	$5.00	$4.25	$87.22	$6.00	$234.72
3	2.25 by 6.54	24.95	95.93	13.50	0.52	3.00	5.00	4.60	87.22	7.50	242.22
4	2.33 by 6.83	35.65	97.02	18.00	0.78	3.00	5.00	5.50	94.00	10.00	268.95
5	2.42 by 4.08	48.75	105.10	21.00	1.04	3.00	5.00	6.25	55.55	15.00	260.69
6	2.50 by 7.03	62.60	113.19	24.00	2.08	3.00	5.00	7.00	103.32	20.00	340.19
7	2.58 by 6.57	80.60	117.77	28.50	2.34	3.00	5.00	7.80	100.00	22.50	367.51
8	2.67 by 7.25	86.50	122.35	33.00	2.60	3.00	5.00	8.40	112.78	25.00	398.63
10	2.83 by 8.46	128.15	137.53	39.00	3.13	3.00	5.00	10.20	138.89	35.00	499.90
12	3.00 by 7.67	164.40	151.67	55.50	3.51	3.00	5.00	11.70	133.33	45.00	573.11
14	3.16 by 8.04	271.50	166.85	63.00	3.90	3.00	5.00	13.40	146.67	55.00	728.32
18	3.50 by 9.28	410.88	202.20	78.00	6.50	3.00	5.00	16.50	186.11	70.00	978.19

Width of trench is determined by allowing 6 ins. for clearance on either side of wood casing.

Depth of trench is determined by taking an average depth of cover for each size of pipe as per records; to which is added the diameter of wood casing plus 4 ins. for clearance.

The item of excavation includes excavation for drain tile 12 ins. by 12 ins. in bottom of trench. The gravel is placed in this trench around the drain tile.

Feb. 1, 1913, Otto E. Trautmann gives a detailed calculation of the saving in coal effected by covering steam pipes in a residence heating plant. He assumes a useful radiation surface of 400 sq. ft., a coal consumption of 15 tons per annum with the basement pipes and boiler covered. Assuming coal to cost $6 per ton he figures that $11 more must be spent for coal if the pipes are left uncovered. This $11 per year can be saved by $45 worth of covering on boiler and basement pipes.

The additional expenditure required for coal with the basement radiating surface uncovered is well shown in Fig. 6.

Labor Costs of Applying Magnesia Covering to Pipes and Fittings.

HIGH-PRESSURE COVERING

	Cost per lin. ft.		Cost each
4-in. pipe	$0.17	1½-in. flange unions	$1.03
8-in. pipe	0.38	4-in. flange unions	1.25
10-in. pipe	0.79	8-in. flange unions	3.19
12-in. pipe	1.25	10-in. flange unions	3.40
8-in. pipe bends	1.03	12-in. flange unions	5.49
	Cost each		
1½-in. elbows	$1.30	1½-in. valve bodies	1.60
8-in. elbows	3.30	8-in. valve bodies	3.28
8-in. elbows	3.58	10-in. valve bodies	3.60
12-in. elbows	4.90	12-in. valve bodies	4.90
4-in. expansion joints	2.60	8-in. valve bonnets	3.25
10-in. expansion joints	5.63	10-in. valve bonnets	3.60
12-in. expansion joints	6.15	12-in. valve bonnets	3.70

LOW-PRESSURE COVERING

	Cost per lin. ft.		Cost each
2½-in. pipe	$0.10	2½-in. flange unions	$1.15
4-in. pipe	0.12	2½-in. tees	1.30
		4-in. tees	1.75
		2½-in. elbows	1.30
		2½-in. valve bonnets	1.98

The above table by Rupert K. Stockwell appeared in Engineering & Mining Journal, March 22, 1913. It was computed from daily records made while covering the high pressure steam heating line 2,400 ft. long running from the power house to the concentrator, and the steam and feed-water lines around two 450-boiler h.p. reverberatory-furnace waste-heat boilers, at McGill, Nev., in October, 1909. The men who did the work were pipe fitters, rated at $.50 per hr., and helpers rated at $.375 per hr., each fitter having two helpers.

The covering was standard magnesia pipe-covering, purchased from the H. W. Johns-Manville Co., and put on in strict accordance with their specifications, the high-pressure covering being 1.5 ins. thick, held away from the pipe by bands of magnesia 1 in. thick, spaced 18 ins. apart. The covering for 10 in. pipe and larger came in keystone-shaped strips; this was placed on the magnesia bands, bound together with wire netting, all cracks plastered with magnesia mud and cement, and the whole covered with canvas; brass bands

were then clamped over the canvas at intervals of 30 ins. and then the whole was painted with a mixture of tar and gasoline. The high-pressure covering for pipe smaller than 10 ins. came in half-cylinders, instead of keystone-shaped strips.

The low-pressure covering, which in this case was all for pipe less than 8 ins. in diameter, came in half-cylinders, 1 in. thick and was placed directly on the pipe, without space rings. The finish was the same as for the high-pressure covering.

The magnesia covering for fittings, valves, expansion joints, and pipe bends, did not come shaped to fit, but had to be sawed and fitted to the work by hand, from magnesia strips and slabs. This was slow and expensive work. It is to be understood, that in the table, where a fitting covering is listed, the flanges are not included; all flanges are figured separately as part of flange unions.

Unit Cost of Steam Heating in Detroit, Michigan. Mr. A. D. Spencer in Power and The Engineer, July 5, 1910, gives the following figures for the live steam central station heating system of the Central Heating Company:—

TABLE IV. OPERATING DATA ON STEAM HEATING

	System "A."	System "B."	Combined
Lbs. steam sold — heating	167,700,000	141,700,000	309,400,000
Lbs. steam sold — power, etc.	41,300,000	5,250,000	46,550,000
Lbs. total steam sales	209,000,000	146,950,000	355,950,000
Electricity sold kw.-hr.	....	4,523,200	4,523,200
Earnings per M. lb. steam	47.5	48.2	47.8
Earnings per M. cu. ft., space	2.10	3.90	3.0
Earnings per sq. ft. radiation	21.4	23.7	22.6
Number of customers	274	396	670
Cu. ft. space	37,200,000	17,300,000	54,500,000
* Sq. ft. radiation	372,400	287,800	660,200
Ratio radiation to space	1–100	1–60	1–83
Cost of coal per ton	2.50	2.55	2.53
Lb. coal per M. lb. steam sold	220	220	220
Lb. steam sold per lb. coal	4.6	4.6	4.6
Lb. steam sold per M. cu. ft. space	4,500	8,200	6,350
Lb. steam sold per sq. ft. radiation	450	490	470
Heating efficiency, per cent.	37	37	37
Steam sold in per cent. of generated	....	....	55.2
Steam used in auxiliaries in % of generated	....	....	19.2
Line losses in % of generated	....	....	9.8
Total sold or accounted for in % of generated	....	....	84.2
Unaccounted for in % of generated	....	....	15.8
	....	....	100.0

* In these figures no allowance is made for hot water heaters, of which there are about 200 on System "B" and 100 on System "A."

Service Rates. These rates were figured on making the cost to the customer about the same as his own cost had been on the theory that with equal cost the advantages of the service would attract the business. Data on 40 residences indicated the average

TABLE V. COST IN CTS. PER 1000 LBS. OF STEAM SOLD

	Plant A	Plant B	Average
Production	32.7	38.0	34.9
Distribution	2.9	3.1	3.0
Sales and collections	0.4	0.4	0.4
General	2.5	3.6	3.0
Injuries and damages	0.1	0.1	0.1
Insurance and taxes	4.2	4.7	4.4
Electricity sold (credit)	..	(15.4)	(6.4)
Total of above items	42.7	34.5	39.5
Depreciation	6.7	8.9	7.6
Interest	11.6	16.1	13.1
Total cost	61.0	59.5	60.2
Profit to make total returns on investment 8%	6.2	8.2	7.0
Total	67.2	67.7	67.2
Earnings	(47.5)	(48.2)	(47.8)

TABLE VI. COST IN CTS. PER SQ. FT. IN RADIATION

	A.	B.	Average
Production	14.7	18.7	16.7
Distribution	1.3	1.5	1.4
Sales and collections	1.2	1.2	1.2
General	1.1	1.8	1.4
Injuries and damages	0.0	0.0	0.0
Insurance and taxes	1.9	2.3	2.1
Electricity sold (credit)	..	(7.6)	(3.0)
Total of above items	19.2	17.0	18.5
Depreciation	3.0	4.4	3.6
Interest	5.2	7.9	6.3
Total cost	27.4	29.4	28.4
Profit	2.8	4.0	3.3
Total	30.2	33.4	31.7
Earnings	(21.4)	(23.7)	(22.4)

TABLE VII. SERVICE RATES

Monthly bills for steam consumption aggregating —	Gross	Net
0 lb. to 12,500 lb.	58	52.2
12,500 lb. to 25,000 lb.	57	51.3
25,000 lb. to 37,500 lb.	56	50.4
37,500 lb. to 50,000 lb.	55	49.5
50,000 lb. to 75,000 lb.	54	48.6
75,000 lb. to 100,000 lb.	53	47.7
100,000 lb. to 200,000 lb.	52	46.8
200,000 lb. to 300,000 lb.	51	45.9
300,000 lb. to 400,000 lb.	50	45.0
400,000 lb. to 500,000 lb.	49	44.1
500,000 lb. to 600,000 lb.	48	43.2
600,000 lb. to 800,000 lb.	47	42.3
800,000 lb. to 1,000,000 lb.	46	41.4
Above 1,000,000 lb.	45	40.5

Minimum monthly charge, 5,000 lb.

cost of coal heating in Detroit to be about $4.60 per thousand cu. ft. of space heated with anthracite coal at $6.75 per ton. It appears that the actual earnings for System B are about 15% under this figure. With hard coal at $7.50 per ton, the customer's cost would be $5.10 per thousand cu. ft.

System A. During the winter of 1909 and 1910 the system served 400,000 sq. ft. of radiating surface, and furnished steam for power and other purposes equal in amount to that required for about 100,000 sq. ft. of radiation. This system was located in the business section and operated with live steam.

System B is in the residential section, and uses the exhaust from three McIntosh & Seymour single-cylinder engines direct connected to generators capable of developing 1300 kw. against the back pressure of the heating system. Service is furnished for about 300,000 sq. ft. of radiation, from Babcock & Wilcox boilers equipped with Jones stokers. The boiler capacity is 2,465 h.p., and the equipment includes multi-generator sets of 1,000 kw. capacity. The generating equipment is operated whenever there is a demand for exhaust steam, some of the direct current generated being used in the district and the remainder being converted and delivered to the 4600-volt transmission system of the Edison Illuminating Company. When the district demand for electricity is greater than the equivalent demand for exhaust steam, the excess current is taken from the transmission lines and converted; and when the demand for steam exceeds the capacity of the engines, live steam is used.

Ordinarily during the winter months it is necessary to furnish some live steam and during the lighting peaks, it is generally necessary to use some electricity from the transmission lines.

The plant includes eight 500 h.p. Stirling boilers, Jones stokers, forced draft, feed-water heaters and ash-handling apparatus, with coal-storage bins of 1500 tons capacity equipped with cranes for handling coal from the alley in five-ton hopper wagons.

Distribution Lines. 15 lbs. per sq. in. was the average pressure in the heating mains to handle some old 15 lb. installations and to do cooking and miscellaneous service. The customers having lower-pressure systems were required to install regulating valves to reduce the pressure. To furnish power to operate steam pumps, etc., a system of 110-lbs. per sq. in. pressure was installed in the heart of the business district, and this system was designed also to use as a feeder for the low-pressure system. The 110-lb. service has proved unsatisfactory, principally for lack of a steam meter.

Steam Loss. The condensation per hr. per sq. ft. of radiation was found to be 0.086 lbs. on 20 lb. lines and 0.051 lbs. on 5 lb. lines, some of these factors being for log construction, no data having been obtained on concrete construction.

Metered Service vs. Flat-Rates for Steam Heating. The habit of establishing flat-rates in the early days of an industry is pretty thoroughly ingrained in the American public and dies hard. The advantage to the customer is that he knows the amount of his monthly bill and consequently feels at liberty to give himself and his family carte-blanche to use all of the service that the company

will furnish without any worry as to the result to him personally. The inevitable consequence is that a great deal of valuable service is wasted and, theoretically at least, the unit cost to the company of the service actually used is higher and rates are higher. It does not always work out exactly in this manner in practice, for the reason that it is enormously difficult to establish the right combination of flat-rates and meter rates in such a way as to do justice to those parties, the consumer and the Company. An illustration of this is furnished by some interesting figures presented in the Electrical World in 1913 for a steam-heating central station in a western town of 8000 population having a considerable number of customers taking a total of 4,577 sq. ft. of radiation on the meter plan and a number of other customers taking 9,843 sq. ft. of radiation on the flat-rate. The ratio of the area of radiation per cubic contents of buildings heated was almost the same for the two classes of customers, being 1 to 86 in one case and 1 to 88 in the other. Revenue per sq. ft. of radiation for the metered customers was about ⅔ of that for the flat-rate customers.

But the metered customers realizing that they were paying for what they actually used consumed rather less than half as much steam per sq. ft. of radiation, the respective figures being given in Table VIII. The data were taken from a considerable variety of industries that received the service.

TABLE VIII. STEAM USED BY METERED AND UNMETERED CUSTOMERS

	Metered customers	Flat rate customers
Condensation per 1,000 cu. ft., lbs.	4262	8795
Condensation per sq. ft. of radiation	368	775
Ratio of radiation area to cubic contents of bldgs.	1:86	1:88
Revenue per 1,000 cu. ft. content of bldgs.	$2.80	$3.95
Revenue per sq. ft. of radiation	0.24	0.35

Prices of Heat from Central Heating Plants. Tables IX to XI give prices of heat from central heating plants as given by various authorities.

TABLE IX. PRICES OF HEAT FROM CENTRAL HEATING PLANTS

(After tables given in Proceedings of American Society of Heating and Ventilating Engineers for 1909.)

State	Steam Per sq. ft., cts.	Steam Per 1,000 lbs., cts.	Hot water Per sq. ft., cts.
Colorado	65	....	....
Illinois	24	....	....
"	....	45	....
"	25	....	....
"	28	....	....
"	25	....	15
"	22.5	....	17.5
"	....	....	15
"	....	....	20

State	Steam Per sq. ft., cts.	Steam Per 1,000 lbs., cts.	Hot water Per sq. ft., cts.
Indiana	....	....	20
"	....	....	18
"	....	....	15.5
"	....	....	12.5
"	....	....	15
"	....	....	17
Iowa	....	....	18
"	....	....	20
"	....	....	15
"	....	50	....
Minnesota	....	60	....
Missouri	....	56	....
"	....	....	25
Montana	60	....	....
New York	....	50	....
"	....	50	....
"	....	42.5	....
"	....	48	....
North Dakota	....	60	....
"	....	40	....
Ohio	....	....	15
"	....	....	15
"	....	....	20
"	....	....	17.5
"	....	50	....
Pennsylvania	25	....	....
"	....	40	....
"	34	....	....
"	33.3	....	....
Rhode Island	....	66	....
Wisconsin	....	....	25
"	....	....	25

TABLE X. PRICES OF HEATING SERVICE FROM CENTRAL STEAM PLANTS

(After table in Bul. 373, U. S. Geological Survey)

No.	Purpose of plant	Total heating surface, sq. ft.	Total length of mains, ft.	Boiler h.p.	Engine h.p.	Pressure on mains, lbs.	Cost of coal per ton	Price of heating cts. per 1000 lbs. of steam
1	H	1,100,000	58,080	11,000	0	55	$2.23	50
2	P	200,000	10,560	4,200	4,000	15	1.00	24*
3	L	138,000	12,000	2,150	2,800	17	1.70	50
4	L	124,000	31,680	1,600	705	4.5	2.50	42.5
5	P	88,611	8,777	950	1,050	4	2.63	40
6	H	83,032	7,920	750	0	5	1.75	56
7	L	70,000	4,000	1,500	250	10	4.60	60
8	P	56,000	13,200	1,500	1,200	2–6	1.00	25*
9	P	50,000	3,000	1,000	1,500	7.5	4.00	60
10	P	45,000	4,000	600	800	55	1.90	25*
11	P	38,267	700	400	200	5.5	2.10	25*
12	P	35,000	2,640	600	400	6–15	1.30	25*
13	P	30,000	3,960	725	700	5	3.75	60

H — Heating only. P — Heat, light and power. L — Heat and light. * Per sq. ft. radiating surface.

TABLE XI. PRICES OF HEATING FROM CENTRAL HOT WATER PLANTS.

(After table in Bul. 373, U. S. Geological Survey)

No.	Purpose of plant	Total heating surface, sq. ft.	Total length of mains, ft.	Boiler h.p.	Engine h.p.	Pressure on mains, lbs.	Cost of coal per ton	Price of heating cts. per sq. ft. of radiating surface
1	P	180,000* / 270,000†	15,840* / 31,680†	2,770	4,100	8*–50†	$0.90	25* 15†
2	P	400,000	.....	1,800	....	30	2.50	20.0
3	P	160,000	47,520	2,800	3,000	45	2.20	15.0
4	P	150,000	.....	2,800	3,200	6	...	22.5* 75.5†
5	P	130,000	34,000	1,000	570	70	1.75	15.5
6	L	120,000	10,560	1,720	2,500	48	1.35	18.0
7	P	115,000	18,480	800	800	60	2.20	17.0
8	P	......	17,500	400	375	88	1.47	20.0
9	P	110,000	21,120	1,400	550	70	1.30	15.0
10	P	100,00	58,080	1,100	1,250	60	1.20	15.0
11	L	85,000	.....	800	425	45–60	1.70	18.0
12	P	80,000	10,560	1,100	750	30	2.25	20.0
13	L	70,658	31,680	600	800	60	2.50	20.0
14	L	70,000	12,000	800	515	50	2.61	15.0
15	L	61,000	8,800	400	150	54	3–2.12	20.0
16	P	60,000	15,840	400	....	40	1.12	12.5
17	P	30,000	7,000	950	1,000	40	1.75	17.5
18	P	20,000	4,000	300	250	30	1.95	15.0
19	P	10,000	4,000	600	800	55	1.90	25.0

P — Power, light and heat. L — Light and heat.
* Steam. † Hot water.

Comparison of Metered and Unmetered Service. J. H. Pepper in Electrical World states that from Table XII it will be seen that customers operating atmospheric systems on a meter basis are by far the most profitable to the central station. In comparing the steam quantities used Mr. Pepper pointed out the fact that the

TABLE XII. STEAM-HEATING SERVICE FOR 26 CUSTOMERS (SEASON 1914–15)

	Total cu. ft. space	Total sq. ft. radiation	Total lbs. condensation per season	Ratio radiation to space	Total lbs. condensation per 1000 cu. ft. of space	Total condensation per sq. ft. of radiation
* Atmospheric system meter	2,940,975	40,265	12,436,000	1 to 73	4.228	308
Other system meter..	1,557,786	20,517	11,156,000	1 to 75	7,161	543
Flat-rate, one-pipe system	945,061	13,332	13,210,000	1 to 70	13,977	990

* Mean temperature during heating season 39.30 deg. F.

flat-rate, one pipe customers regulate their room temperatures by opening or closing windows, while those with atmospheric systems use the radiator valves to regulate the flow of steam to their radiators.

The one-pipe customers and those designated as having "other systems" are not receiving the best of service in spite of the fact that 2 lbs. to 4 lbs. pressure is being maintained at the services. The customers with atmospheric systems require but from 3 oz. to 6 oz. pressure to receive good service. The atmospheric system employs no cooling coil, yet the condensate going to the sewer varies in temperature between 90 deg. F. and 110 deg. F. Other systems with cooling coils deliver the condensate to the services at temperatures ranging between 160 deg. and 200 deg. F.

TABLE XIII. COST OF STEAM IN HEATING PLANTS

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Number of days	15	4	5	4	46	151
Steam gen., 1,000 lbs......	1611	362	485	124	10,310	36,890
Tons of coal, gross......	117	27.6	30.3	11.3	783	2540
Rate of evaporation......	6.15	5.84	7.13	4.94	5.89	6.31
Av. outside temp.........	30.7	34.2	39.6	37.0	34.8	40.9
Boiler capacity h.p.......	384	600	600	800	1200	900
Max. boiler h.p. delivered.	280	300	330	150	600	850
Av. boiler h.p. delivered...	100	80	150	50	235	350
COST PER 1,000 LBS. OF STEAM						
Coal	$0.191	$0.201	$0.165	$0.238	$0.203	$0.187
Labor	.049	.085	.079	.251	.052	.056
Ash removal	.010	.011	.009	.021	.008	.007
Water (makeup)	...	...	...	...	.007	.001
El. cur. (forced dr.)	.014	.005	.007	.021	.008	.006
El. cur. (b.f. pump)	...	...	.007	...	...	...
Supplies	.004	.011	.006	.002	.004	.006
Repairs and misc.	.004	.004	.002	.001	.003	.002
Total	$0.272	$0.317	$0.275	$0.535	$0.285	$0.265
Fixed charge on investment	.029	.051	.054	.084	.044	.033
Total cost per 1,000 lb.	$0.301	$0.368	$0.329	$0.619	$0.329	$0.298

New York City Heating Costs. A report of the Station Operating Committee, National District Heating Association (1915) shows operating costs for heating 6 New York City buildings given in Table XIII. As all are largely heating plants, the load is subject to all the vagaries of the weather. The extremely variable loads of the early spring and fall, with the excessive standby losses and transient labor force, are in part responsible for the low evaporation. The high cost of steam per 1000 lbs. does not mean a high total cost for the season. Out of the 5040 hrs. (Oct. 1 to Apr. 30) making up the nominal New York heating season, steam is actually needed from 3,000 to 3,500 hrs., in buildings occupied from 12 to 18 hrs. daily. This small total consumption results in a low total cost for the season in spite of the unit cost.

In several instances where the results cover a short period, the apparatus for weighing coal and water had but recently been

installed. Such tests do not, of course, represent the performance throughout the year, but do convey an idea of the possible economy. In all the plants No. 3 buckwheat coal delivered at $2.50 a ton is burned with a balance draft.

No. 1 is a 25-story office building, covering a plot about 9000 sq. ft. The boiler plant, consisting of two Heine water-tube boilers operated at 70 lbs. pressure, supplies steam for cooking, heating and hot-water service. The plant is shut down during the summer and the steam for cooking purchased.

No. 2 is a large, 12-story loft building containing about 4,000,000 cu. ft. Steam is used for manufacturing in large amounts throughout the year, 24 hrs. a day. The boiler plant is made up of three fire-tube units.

No. 3 is a new office building 25 stories high, with a volume of about 6,500,000 cu. ft. The equipment for heating and hot-water service consists of two Erie City water-tube boilers, operated at 30 lbs. pressure. The boiler-feed, vacuum and sump pumps are operated by electric motors. The boilers are shut down during the nonheating season and hot water is supplied by a small heater.

No. 4 is a loft building in the old commercial section of New York. This building has only recently had supervisory service. The figures show extravagance in the labor costs and the use of forced draft in burning the coal. This case illustrates the too frequent condition where continuity of service is the only consideration given the power plant.

No. 5 is a large department store of about 15,000,000 cu. ft. contents. Four B. & W. water-tube boilers supply steam for cooking, refrigeration, operation of a cash-tube system, hot water and heating.

No. 6 receives steam from a boiler plant 750 ft. distant. The load is fairly constant day and night during the heating season. The plant is operated (only when heating is required) by three B. & W. units at 100 lbs. pressure. The boiler-feed water comes from a heater at a temperature well over 200 deg. F. The load conditions and the general design for this plant permit fairly satisfactory operation, as may be seen from the costs.

Cost of Making Steam for Building Heat. Some comparative data on the cost of operating heating plants taken from the operating records of a number of installations in New York City were presented by George W. Martin in a paper before the American Society of Heating and Ventilating Engineers and printed in Electrical World, Feb. 26, 1916. A summary of the results of tests made during the past summer on a 150 h.p. return-tubular boiler using different grades of anthracite coal available in New York City is given in Table XIV. These results show the lowest cost for generating 1000 lbs. of steam when using No. 3 buckwheat coal.

All the plants are largely for heating, hence the load is subject to the vagaries of the weather.

In most of the cases discussed the boiler grates were originally installed for burning No. 1 buckwheat with natural draft. The change in the setting for burning No. 3 buckwheat involved the

TABLE XIV. RESULTS OF COMPARATIVE COAL TESTS

	No. 3 buck-wheat	No. 2 buck-wheat	No. 1 buck-wheat	Pea coal	Soft and No. 3 buck-wheat
Moisture in coal as received..	6.9	8.0	4.8	3.4	8.3
Volatile per lb. dry coal.....	7.9	9.3	7.2	7.1	12.6
Fixed carbon	76.9	75.3	75.9	74.2	75.4
Ash	15.4	15.4	16.9	18.7	12.0
B.t.u.	12,423	12,080	12,140	11,961	12,944
Length of tests, hours......	24	24	24	24	24
Total dry coal consumed, lbs.	4,800	5,514	5,171	5,531	4,400
Per cent. ash and refuse....	18.6	17.1	17.0	16.8	14.3
Total water fed to boilers, lbs.	42,988	46,275	46,335	51,395	45,045
Factor of evaporation......	1.08	1.074	1.077	1.083	1.076
Equivalent water from and at 212 deg.	46,427	49,699	49,903	55,712	48,468
H.p. developed	56.1	60.0	60.3	67	58.5
Builders' rating	150	150	150	150	150
Per cent. of builders' rating developed	37.4	40	40	44.8	39
Efficiency of boiler and grate	75.6	72.3	77.1	84.8	82.5
Cost of coal per net ton....	$2.22	$3.15	$3.65	$4.40	$3.15
Fuel cost of 1000 lbs. steam, cts.	13.25	20.4	21.4	23.5	16.8
Fuel cost from and at 212 deg.	12.26	19.0	19.8	21.7	15.6

building of a hollow bridge wall with a cast-iron air box and damper set in the front of the wall at the back of the ash pit. A motor-driven blower was set outside the boiler at one end of the bridge wall, a hand-controlled rheostat being used to vary the speed of the blower-motor. The grates installed were of the dumping type and contain about 10 per cent. of air space. The cost of the installation of grates, motor-driven blower, rheostat and rebuilding the bridge wall averaged $3 per boiler h.p. No. 3 buckwheat coal, bought in wholesale quantities, costs, delivered in the bunker, between $2.35 and $2.50 a net ton. The coal is from the Scranton district of the Pennsylvania anthracite region and runs from 12,300 to 12,900 B.t.u. and from 16 to 13% ash. A poor grade of No. 3 buckwheat, it is stated, has no advantage over a better grade of No. 1 or No. 2 buckwheat, so that unless a good quality of coal can be assured it is useless to attempt economies by burning the smallest size of anthracite, even when it is mixed with soft coal.

Rates for Central-Station Hot-Water Heating Allowed by the Public Service Commission of Ohio. The following rates were ordered into effect as of Sept. 15, 1913.

For indirect radiation 40% of these rates are to be added.

Amount of radiation installed	Cost of radiation per season, per sq. ft.
0 to 500	$0.20
500 to 2000	0.1888
2000 to 5000	0.1777
5000 or over	0.1666

Rule of the Commission for Determining the Sq. Ft. Radiation Required to Heat a Building: Determine the area of the exposed

walls of the building and from this subtract the area of windows and door openings (frame measurements). Divide this remainder by the wall constant given in Table XV and to the quotient add the area of window and door openings (frame measurements). Multiply this sum by 75 and to the product add the cubic contents of the room. Multiply the sum last obtained by the temperature constant in Table XV. The result will be the sq. ft. of cast-iron radiation required to heat a building of good construction. Any room or space having an opening which may communicate with the rooms to be heated must be included in the measurement for space heated, whether radiation be installed or not.

TABLE XV. WALL AND TEMPERATURE CONSTANTS

For ⅞-in. wall	1
For 2-in. wall	2
For 4-in. wall	3
For 6- to 9-in. wall	5
For 9- to 10-in. wall	7
For 13- to 27-in. wall	8
For 65 deg. F.	0.0075
For 70 deg. F.	0.0082
For 75 deg. F.	0.009

The rule is for ideal conditions and to the radiation requirement determined by its use, there must be added a percentage to provide for exposed locations, bad construction, insufficient or improper repairs and other conditions which would make the minimum radiation requirement inadequate to keep the building comfortably warm. For these conditions which cannot be ascertained by general rule add from 5 to 25% to the minimum for ideal conditions.

It is specified that the heating company must furnish hot water in sufficient quantity to heat the building to a temperature of 70 deg. F. in the coldest weather, provided that sufficient radiation be installed by the consumer to maintain the desired temperature. Evidence of the sufficiency of the quantity of water shall be that the temperature of the hot water has not dropped more than 30 deg. F. while passing through the consumer's heating system, as shown by not less than four tests taken 15 mins. apart in succession, the tests to be made at the point of entrance of service to the building.

Surface area of all hot-water pipes installed in the basement or elsewhere not included in the measurement for radiation will be charged for as radiation, unless covered with at least 1-in. covering.

This decision prescribing the rules given above was handed down in the case with the Toledo Railway and Light Co., and quoted in Power, June 17, 1913.

Comparative Cost of Heating a 25-ft. Car, 45 Ft. Over All, by Hot Water and by Electricity, Based on Operating Conditions on a 32-Mile Interurban Railway. The following figures were contained in a letter of Daniel W. Smith, president of The Peter Smith Heater Co., addressed to the Electric Railway Journal, May 15, 1909.

TABLE XVI. COMPARATIVE COST OF HEATING CAR

Conditions	Hot water	Electricity
Weight of car with load, tons	28	28
Schedule speed, miles per hr.	20	20
Car-miles per day per car	240	240
Cost of heating equipment installed	$175	$75
Weights of heating equipment, installed, lbs.	1400	225
Cost of electric power (at power station) per kw.	$.0135	$.0135
Watt-hours at power station, per ton-mile	125	125
Heating season, days	180	180
Hours per day heating	18	18
Moving car equipment per ton-mile (at power station)	$0.0017	$0.0017
Moving heating equipment during heating season, per day	$0,306	$0.0459
Weight of heating equipment during summer, lbs.	840	225
Moving heating equipment during summer day, per day	$0.18	$0.0459
Heater coal consumed per day, lbs.	55	....
Cost heater coal per day at $7.50 per ton	$0.206	....
Attendance for the season	$9	$2.70
Interest and depreciation at 10% heating equipment	$17.50	$7.50
Repairs figured at, per cent	3	2
Cost of repairs	$5.25	$1.50
Increased feeders required	2.70	20
Yearly cost feeders, interest and depreciation, at 7½%	$6.06	$37.50
Maximum current capacity of electric heater, amp.	....	18
Average k.w. at station, electric heater	....	5
Cost electricity per day, electric heater	....	$1.21
Summary:		
Interest and depreciation on heater equipment	$17.50	$7.50
Repairs of heater equipment	5.25	1.50
Attendance	9.00	2.70
Interest and depreciation on extra feeders	6.06	37.50
Elec. hauling heating equipment for one year	88.70	16.75
Cost of coal consumed in one year	37.08	....
Cost of electricity used in heater for one year	....	217.80
Yearly cost	$163.59	$283.75
Difference in favor of hot-water heaters		$120.16

These tests were made by the Green Bay Traction Company, Green Bay, Wis., and are based on a small interurban car running at a schedule speed of 20 miles per hr.

Comparative Costs of Car Heating. The following by Messrs. Thorn, Benedict, and Clark was published in Electric Railway Journal, Oct. 14, 1911. To bring out clearly the comparison in costs of heating a car by the 3 modern systems, the accompanying estimate may be of interest. The figures in each case are based, in general, on results obtained in practice and are considered fair and reliable.

Assumptions. 32-ft. car body; heating season, 145 days; lowest temperature, about zero; municipal requirements, 50 deg. F.; cost of power, 1.4 cts. per kw.-hr. at the trolley; cost of coal, $7.75 per ton.

Under the conditions assumed, the relative total economy of the 3 principal heating systems is as follows: Hot air system, first; hot water, second; and electric, third.

In figuring the power consumption of electric heaters the following method will probably give the most accurate results. Obtain from the weather bureau temperature readings for each winter for several years. Plot a curve showing variation of temperature for each day of heating season. Find what point of heat is carried for the different temperatures and then a power curve can be plotted from which the average k.w. per day can be readily obtained.

In the use of hot-water or hot-air heaters there is a tendency on the part of the car crew to use less coal than would have to be used if the cars were kept at a uniform temperature during the time they are in service, where with electric heaters the tendency is to put on 3 points when 2 points would suffice. This gives rise to false ideas of the relative costs of the various heating systems.

In the installation of electric heaters it is preferable to have a comparatively large number of heaters rather than a few, even though the power consumption is on the same basis, on account of the better distribution of the heat. For localities where the temperature reaches zero or lower it is well to have about 4.5 watts per cu. ft. of car body, otherwise it may be difficult to keep the cars comfortable when low temperatures prevail.

When a practical, low-cost heater regulator is brought out and comes into general use the cost of electric heating will be very largely reduced. Tests have been made which indicate that the saving in power by the use of thermostat regulators will be in excess of 50%.

The cost of car heating would be somewhat reduced and the comfort of passengers considerably increased if storm sashes were more generally used. The difference in temperature on some cars in the Middle West with the same heating equipment—one with storm sashes, one without, and running together on the street — was about 9 deg. F.

The maintenance of heating systems would be greatly reduced if more care were given to the installation of new equipment. This is particularly true of electric heaters.

TABLE XVII. TOTAL COST FOR ONE YEAR CHARGEABLE TO CAR HEATING

	Electric heater	Hot water heater	Hot air heater
Cost of power	$137.03	....	$8.22
Repairs and maintenance	1.09	$4.35	2.90
Interest and depreciation	8.80	18.75	18.60
Coal	.....	47.76	47.76
Labor of attendance	.....	8.70	8.70
Hauling (4 cts. per lb. per year)	20.00	60.00	20.00
Insurance charge	.....	12.00	12.00
Total cost per car	$166.92	$151.56	$118.18

The above figures are based on the following data and assumptions:

	Electric heater	Hot water heater	Hot air heater
First cost, installed	$80	$125	$155
Interest and depreciation	5% and 6%	5% and 10%	5% and 7%
Weight installed...	500 lbs.	1500 lbs.	500 lbs.
Coal consumption per day	....	85 lbs.	85 lbs.
Power consumption	5.0 kw. average for heating season	....	0.3 kw.
*Repairs and maintenance	¾ c. per day	3c. per day	2c. per day
Cost of car.......	$6,000	$6,000	$6,000
Investment in barns per car	$1,500	$1,500	$1,500
Hours per day per car	13½	13½	13½
* Labor of attendance	....	6c. per day	6c. per day
Heating season....	145 days	145 days	145 days
Extra insurance over electric heaters on barns....	....	10c. per $100	10c. per $100
Extra insurance over electric heaters on cars	....	17½c. per $100	17½c. per $100

* Per day of heating season.

Cost of Heating Cars by Electric Heaters Compared with Coal, as determined by tests made by the Cleveland Railway and the City Street Railroad Commission printed in Electric Railway Journal, June 8, 1912.

TABLE XVIII. ESTIMATED COST OF POWER FOR ELECTRIC HEATER FOR TRAIL CARS ON BASIS OF ONE CAR PER YEAR

Maximum demand at car from test (500 volts)..........	11.00 kw.
Maximum demand at d. c. bus substation (90% efficiency of distribution)	12.23 kw.
Maximum demand at generator bus (89% efficiency of transmission and conversion)	13.76 kw.

12.23 kw. for 2¼ hrs. requires 8.16 kw. of substation capacity, 50% overload allowed.
Investment in substation, 8.16 × $25 = $204.00.
($25 per kw. of capacity installed.)
Fixed charges on substation equipment, $204 × 10% = $20.40.
(Includes 5% interest, 2.52% amortization, 1.36% taxes = 9.88% or 10% used.)
Investment in distributing system is $41.70 per kw. of maximum demand.

Investment in distributing system per car, $41.70 × 12.23....	$510
Fixed charges per car year, $510 × 10%	51
Maintenance of distributing system per kw. of maximum demand per year	2
Maintenance of distributing system per car................	24.46
Consolidated car heaters require 4661 kw.-hr. at car or at generator bus, 4661 ÷ .80 = 5830 at $0.0038...........	22.15
Substation operation and maintenance, 5190 × $0.0003......	1.56
Peter Smith forced draft heater required 4172 kw.-hr. at car, or 4172 ÷ .80 = 5220 kw.-hr. at generator bus, 5220 × $0.0038	19.80
Substation operations and maintenance, 4640 × $0.0003.....	1.39

Summary of power cost.	Consolidated electric heater	Peter Smith electric heater
Demand charge for power, 13.76 kw. for 6 months	$82.50	$82.50
Energy charge	22.15	19.80
Substation operation and maintenance	1.56	1.39
Fixed charge on substation	20.40	20.40
Fixed charge on distributing system	51.00	51.00
Maintenance of distributing system	24.46	24.46
	$202.07	$199.55

Peter Smith coal heater:	
Fixed charge, 182 kw. at $16.22	$2.95
Substation operation and maintenance, 148-kw.-hr. at $0.0003	.04
Energy charge, 166 kw.-hr. at $0.0038	.63
Total	$3.62

"Three types of heaters were tested, namely, straight electric heaters, the forced ventilation electric heater and the forced ventilation coal heater.

"The tests were made upon 3 of the railway company's 900-type cars, having an over-all length of 52 ft., the front vestibule being inclosed and the rear vestibule open. Each type of heater was installed in a separate car. The tests were made with the cars end to end on a track in the shops of the railway company. Two side ventilator sashes in the front of the car and two in the rear were open during the entire test. The straight electric heater system manufactured by the Consolidated Car Heating Company was installed on car No. 909 and consisted of 26 heaters, installed underneath car seats, 1 main switch cabinet, 1 magnetic switch, 1 thermostat and 1 snap switch. The forced ventilation electric heater, manufactured by the Peter Smith Heater Company, installed on one car, consisted of a compact electric heating unit in a sheet steel housing, equipped with a Sturtevant multivane blower, size C, direct-connected to a 220 volt, 8 amp. series-wound, ball-bearing motor. The cold air taken from underneath the car is blown over the heating coils and distributed from a hot-air duct extending the length of the car body. This heater in service would be installed with an interrupter and thermostat to regulate the temperature of the car automatically. The forced ventilation coal heater installed on another car was also manufactured by the Peter Smith Heater Company and is similar to the heater described above, except that the heat is generated by the direct combustion of coal, the cold air being blown over the combustion chamber.

"The tests run on the 2 electric heaters show that in order to maintain a temperature within the car 41.9 deg. F. above the surrounding air it is necessary to expend about 10,900 watts, or 267 watts for each degree rise of temperature.

"The mean temperature of Cleveland for 40 years for each of the winter months was obtained from the United States Weather Bureau, and the number of degrees of heating required to maintain a temperature of 55 deg. F. inside the car was determined.

It was also assumed that the current must be turned on the heaters a sufficient length of time to raise the temperature to 45 deg. F. before the car goes into service, also that the car remains in service 2 hrs. in the morning and 2 hrs. in the evening."

In the comparison of costs of electric and coal heaters, the contract under which the Cleveland Railway purchases energy was used for determining the cost of the electric heaters.

In building the fire in the coal heater, the following material was used: Kindling, 1.76 lbs.; ash wood, 4.25 lbs.; kerosene oil, 0.312 lbs.; shavings, 0.004 lbs.; coal, 35.29 lbs.

In the general summary, each heater was charged with interest at 5%, taxes at 1.36%, and repairs and maintenance at 1 ct. a day. Depreciation was charged at 7% in the case of electric heaters and 10% in the case of coal heater. The latter was also charged with the following special costs per year:

Coal	$21.00
Fuel and labor of kindling fire thirty times	4.09
Labor of attendance	8.76
Removing and reinstalling heater each season	1.00
Transportation and storage in summer	.50
Value of space occupied by heater	11.16

The final figures showed the Peter Smith coal heater to be far more economical than either electric heater.

In regard to weight and space occupied and a general summary the report says:

"The weights of the various heaters installed complete are as follows: Consolidated, 457 lbs.; Peter Smith electric, 350 lbs.; Peter Smith coal heater, 544 lbs.

"The cost of power for handling the equipment for this trailer service amounts to 2.18 cts. per lb. per year. The Consolidated electric heating equipment is carried throughout the year, while with the Peter Smith forced ventilation heating equipments the heating duct alone is carried throughout the year, the heater being removed and stored during the summer season.

"Either of the electric heaters installed in a car would be placed under the seats, while the coal heater during 6 months of the year occupies the space of one seat in the car; the value of this space is chargeable against this heater. In order to obtain this value it was assumed that the standing capacity of the car is one-half as valuable as the seating capacity. Thus in this car, seating 60 passengers and providing standing room for 60 more, the value of one seat space is one-ninetieth of the value of the car space. On a basis of 38 miles per day for a trailer 156 days per year, the mileage per heating season is 5920, which at 17 cts. per car mile operating cost amounts to $1006.40. Therefore $11.16 is the value of the space occupied by the coal heater during the winter season.

Summary. "Each of the 3 types of heaters has its individual advantages. The electric heaters afford the advantage of cleanliness, convenience and ready means of obtaining automatic regulation of the car temperature. The Peter Smith electric heater has

the important additional advantage of providing a forced ventilation of about 12,000 cu. ft. of fresh warm air per hour. On the Peter Smith electric heater, however, no means were provided for automatically cutting off the current of the heating unit in case of failure of the blower motor, which would probably mean a burn-out of the heating unit. Both of the electric heaters have the disadvantage of being unable to heat the car properly in extreme weather. The curves show that in zero weather it would be impossible to maintain a temperature of more than 40 deg. F. inside the car. With the coal heater a rise of over 48 deg. was obtained easily without any attempt at crowding the heater. The exceptionally high cost of power for heating the tripper cars electrically at rush-hour periods of the day for the climatic conditions existing in Cleveland renders the operation of electrical heaters extremely uneconomical if not prohibitive."

Cost of Car Heating by Electricity and by Hot Water in the Standard Cars of the Chicago City Railway Company. In a booklet issued by the Chicago City Railway Company descriptive of its new standard car, the following data concerning the cost of hot-water and electric heating of cars are given. These figures were used in deciding upon the method of heating to be employed in the new cars. The results show 7 cts. per day per car in favor of electric heating, and this method was adopted:

Average hours per car per day, 9.
Average current per car, 12 amps.
Weight of electric heaters, 360 lbs.
Weight of hot-water heaters, 1454 lbs.
Coal consumed by hot-water heaters, 80 lbs.
Price of coal, $8 per ton.
Price of electric heaters, $80 per car.
Price of hot-water heaters, $140 per car.
Repairs on electric heaters, 5 cts. per car per day.
Repairs on hot-water heaters, 10 cts. per car per day.
Attendance on hot-water heaters, 10 cts. per car per day.
Average miles per car per day, 100 miles.
Average heating season, 150 days.

Upon this assumption, without going through the calculations in detail, the result may be summarized as follows:

Electric Heaters. Cost per day of heating season using electric heaters:

	Cents
12 amps., 9 hours = 54 kw.-hrs. per day, at .992 cts.	53.6
Interest at 5%, plus depreciation at 7%, on $80, cost price of heaters 365 days, divided by 150 days heating season	6.4
Hauling dead weight, 360 lbs., 100 miles per day, 365 days per year, at 0.95 cts. per day of heating season	4.2
Repairs at 5 cts. per car per day	5.0
Interest 5%, plus depreciation 3% on additional copper required for electric heaters per day of heating season	3.8
Total cost per car per day	73.0

Hot-Water Heaters. Cost per day of heating season using hot-water heaters:

	Cents
80 lbs. coal at $8 per ton	32.0
Interest at 5%, plus depreciation at 7%, $140	11.2
Hauling dead weight, 1454 lbs., 100 miles per day, 365 days in year, per day of heating season	16.8
Repairs	10.0
Attendance	10.0
Total cost per car day	80.0

Cost of Car Heating. Foster's Electrical Engineer's Pocket Book, Table XIX, compiled by Mr. McElroy from data of the Albany Railway Company.

Average fuel cost on Albany Railway, per amp. hr. = .241 cts.

Average total cost for fuel, labor, oils, waste, and packings per amp.-hr. = .423 cts.

TABLE XIX. COST OF FUEL PER HOUR FOR HEATING A CAR WITH ELECTRIC HEATERS WITH COAL AT $2 PER 2,000 LBS.

	Position of switch				
	1st	2nd	3rd	4th	5th
	Amperes equal				
	2.14	2.88	6.88	8.09	12.0
	cts.	cts.	cts.	cts.	cts.
Simple, high speed condensing	0.43	0.58	1.40	1.62	2.41
Simple, low speed condensing	.40	.54	1.30	1.51	2.24
Compound, high speed condensing	.39	.52	1.27	1.47	2.20
Compound, low speed condensing	.36	.48	1.17	1.36	2.03

AVERAGE COST PER DAY FOR STOVES

	Cents
33 lbs. coal at $4.55 per ton	$0.075
Repairs	.005
Dumping and removing coal and ashes, coaling up and kindling fire, including cost of kindling and part of cleaning car	.100
Removing stoves for summer, installing for winter, repairing head linings, repainting, etc., av. per day	.0125
Total	$0.1925

Cost of House Heating by Electricity. Frederick A. Osborn in Electrical World, Dec. 23, 1916, states: The house was ordinarily heated by an 024 Standard hot-air furnace. For the past 3 years a high grade of lump coal had been used, costing for the present year $7.75 per ton in the basement bin. The average cost of heating the house, including the wood used in the fireplace, had been about $75 a year for the last three years.

All the rooms heated were equipped with the wire-resistance convector type of electric heater. There were five American heaters and two Hot Point heaters. In the dining room a hot-water radiator to which was attached an induction-type electric heater, was used during a part of the time.

The living room, with a volume of 2,400 cu. ft., had two 3,000-watt heaters, with three heat controls. The maximum wattage was 2.5 watts per cu. ft.

The study, a room of 1,300 cu. ft., had one 600-watt heater. The power taken per cu. ft. was 0.46 watt. The temperature of the study seldom was above 64 deg., and this was by choice.

The dining room has a volume of 1410 cu. ft. It was supplied with one 2000-watt heater, and for a part of the time a 2500-watt water radiator was used. The maximum demand was 1.4 watts per cu. ft.

The kitchen and pantry, with a volume of 500 cu. ft., had a 1000-watt heater. This heater was for most of the time on the low heat, taking about 300 watts, the gas range when the oven was in use furnishing the necessary heat.

The south bedroom, volume 1320 cu. ft., had one 2000-watt heater. This room is used also as a sewing room, and is warmed nearly every afternoon.

The bathroom on the north, with a volume of 350 cu. ft., was supplied with one 1000-watt heater, kept on the low heat most of the time.

As the entire test was carried out with one type of heater, the question will naturally rise, may not some other type of electric heater be more efficient than the type used?. Electric heating differs from all other systems of heating in that all electric heaters of the same wattage are equally efficient. They will all deliver the same number of heat units to the room. In furnace heating the amount of heat escaping up the chimney depends upon the furnace, the method of firing it and other factors not constant. The heat given to the room is that which is not lost in the furnace, the flues and the transmitting pipes from furnace to the room. Coal furnaces deliver from 40% to 60% of the heat in the coal to the rooms.

Electric heaters, on the other hand, deliver practically 100% of the heat to the rooms. For each kw.-hr. of electrical energy put into any type of electric heater, the same amount of heat is furnished. There may be some minor advantages in using one type of electric heater in preference to another type, but this advantage never consists in getting more or less heat units from a kw.-hr. of electrical energy. This fact needs to be kept constantly in mind when discussing the advantages of electric heaters.

Throughout the entire test a recording thermometer giving continuous readings of the temperature was kept in the same position in the living room.

The outside temperature was taken from the recording thermometers at the university after a recording thermometer at the house gave evidence that the outside temperature at the house and the university did not differ by more than a degree.

The dining room thermometer as well as the one in the study were used in each part of the test to determine the similar heating conditions under the two systems, and when this was established they were read only occasionally.

This test was begun Dec. 1 and continued until Jan. 19. During this period Seattle had the coldest weather of the season. The coal used was carefully weighed, part of the time daily, and later

TABLE XX. TEST WITH HOT-AIR FURNACE

Week of	Average outside temperature, deg. F.	Average living room temperature 8 a.m to 10 p.m., deg.	Average living room temperature 10 p.m. to 8 a.m., deg.	Coal consumption, lbs.
December 1– 8	49.2	67.7	62.8	631
December 8–15	43.5	65.7	60.0	667
December 15–22	44.0	65.8	61.1	560
December 22–29	39.5	65.8	61.0	660
December 29–January 5	29.4	66.0	59.0	780
January 5–12	33.0	65.0	58.0	755
January 12–19	29.0	67.0	58.0	837

the coal for two or three days' burning was weighed at one time. In Table XX is found the record of the test.

The average outside temperature for the seven weeks was 38.2 deg. F., the day room temperature was 66.1 deg. F. and the night room temperature was 59.9 deg. F. During the day the room was maintained at an average temperature of 27.9 deg. F. above the average outside temperature. The total coal consumption was 4890 lbs., or an average of 698 lbs. per week. The total cost of the coal at $7.75 a ton was $18.95, or an average of $2.42 per week.

This part of the test began on Feb. 1 and continued until March 14. The detailed record appears in Table XXI.

TABLE XXI. TEST WITH ELECTRIC HEATING

Week of	Average outside temperature, deg. F.	Average living room temperature 8 a.m. to 10 p.m., deg. F.	Average living room temperature 10 p.m. to 8 a.m., deg. F.	Kilowatt-hours used
February 1– 8	36.3	67.0	57.5	1039
February 8–15	46.7	67.3	60.0	741
February 15–22	41.9	66.0	58.4	575
February 22–29	40.5	66.5	56.4	573
February 29–March 7..	36.0	64.0	56.0	794
March 7–14	47.6	66.5	57.6	522

The average outside temperature for the six weeks was 41.5 deg. F., the day room temperature 66.2 deg. F, the night room temperature 57.6 deg. F. The living room was maintained at an average temperature of 24.7 deg. F. above the outside temperature. The total number of kw.-hrs. used was 4274, or an average of 712.3 per week. The cost for the six weeks at 1 ct. a kw.-hr. was $42.74, or an average cost of $7.12 per week. To this cost should be added $2.50 for heating by gas the water used for domestic purposes. The furnace having a water coil in it furnished the hot water in the first test.

If we assume that the loss of heat from a room is proportional to the difference in temperature between the outside and the inside, then the furnace furnished to the rooms $^{27.9}/_{24.7} = 1.12$ or 12% more heat, and the consumption of electric energy for the same amount of heat would have been 4787 kw.-hr. Taking into consideration then the cost for water heating and for furnishing the

same amount of heat, the cost for electric heating under the same conditions as obtained during the furnace heating would have been \$50.37, or \$8.39 per week. This makes electric heating cost 3.46 times that for coal under like conditions.

From this test, electricity selling at 0.29 cts. per kw.-hr. would furnish heat for the same cost as coal at \$7.75 a ton. To many the advantages of electric heating are worth a 50% increase in the cost of heating, and electricity at about one-half a cent per kw.-hr. would make this possible.

A lower rate is usually given by electric companies for "off-peak" loads. In the winter the peak load comes on about 4 o'clock in the afternoon and lasts for four or five hours. If the customer using electricity for heating is to receive this low off-peak rate, some means must be provided for storing up a surplus amount of heat to be drawn on during the time the current is cut off from the heating system. Storage tanks using water are in use, but as far as the writer is informed no entirely satisfactory storage system has as yet appeared. The off-peak service compels the use of liquid-filled radiators, and makes electric heating no more flexible than the hot-water or steam systems.

Comparative Operating Costs of Gas and Electric Cooking. (Report of Heating Committee, Association of Edison Illuminating Companies, September, 1905, from Foster's Electrical Engineer's Pocket Book)

The comparative operating cost of electric and gas cooking depends upon two questions — the relative rates for gas and electric heat units, and the relative heat efficiencies of gas and electric apparatus. A third quantity — the effect produced by the different rates and modes of heat applications in the two classes of utensils — may affect the efficiency slightly, but the existence of this effect is not yet verified.

Starting with the heat of coal, which may be fairly estimated as 12,000 B.t.u. per pound, we compute the relative efficiency of the heat conversion as follows:

Gas	Electricity
1 lb. coal produces 5 cu. ft. gas	1 lb. coal produces 0.25 k.w.
5 cu. ft. gas contain 3000 B.t.u.	0.25 k.w. contains 853 B.t.u.
Efficiency heat conversion is $3000/12000 = 25\%$	Efficiency heat conversion is $853/12000 = 7.1\%$

$$\frac{\text{Efficiency electrical heat conversion}}{\text{Efficiency gas heat conversion}} = 28.4\%$$

With manufacturing processes of equal cost per pound of coal converted, it is apparent, then, that an electric heat unit must cost nearly four times as much as a gas heat unit, but with present processes the relative rates are:

Gas	Electricity
\$1.00 per 1000 cu. ft.	\$0.10 per k.w.-h.
1 B.t.u. .000167 cents	1 B.t.u. 0.00293 cents

$$\frac{\text{Electric B.t.u. } 0.00293}{\text{Gas B.t.u. } 0.000167} = 17.5$$

It is known that the efficiency of electrical apparatus is about four times that of gas, and, consequently, as the gas utensil requires four times as many B.t.u. the above figure of 17.5 is reduced to 4.4. If, then, the rate for electricity is reduced to one quarter of that assumed, or 2.5 cts. per kw.-hr., this figure of 4.4 is changed to 1.1, and we have practically identical operating costs.

Comparison Between Gas and Electric Rates. According to James I. Ayes (report for National Electric Light Association, May, 1904) electric heat at an average efficiency of 70% equals 0.4197 kw.-hrs. per 1000 effective heat units, and for 105,000 effective heat units there would be required 44.065 kw.-hrs. to give the same results. To compete with gas at equal rates, electricity will have to be sold

at 5.67 at per kw.-hr. where gas is at $2.50 per 1,000 cu. ft.
at 4.54 at per kw.-hr. where gas is at 2.00 per 1,000 cu. ft.
at 3.40 at per kw.-hr. where gas is at 1.50 per 1,000 cu. ft.
at 2.83 at per kw.-hr. where gas is at 1.25 per 1,000 cu. ft.
at 2.27 at per kw.-hr. where gas is at 1.00 per 1,000 cu. ft.

The above is as fair a comparison as can be made where exact figures cannot be secured. The results above quoted have been checked by records made in the same family alternately using gas and electricity each week for considerable periods in a number of cases, and from a variety of records obtained otherwise. It is assumed that suitable equipments both of electric and gas appliances are used.

Cost of Electrical Cooking for an Average Family. (From Foster's Electrical Engineer's Pocket Book.)

Cost of Electric Cooking. The American Handbook for Electrical Engineers gives the following: The average consumption per person per meal ranges from about 0.2 to 0.8 kw.-hr., which at 3 cts. per kw.-hr., corresponds to a cost per person per meal of from 0.6 to 2.4 cts. The actual cost in any particular case of course depends upon the number of persons served, the food cooked and the kw.-hr. cost.

The Cost of Cooking by Electricity. The National Electric Light Association, June, 1912, gives the following: In connection with the installation of the electric range in the residence of Mr. Charles H. Williams, General Manager Northern Colorado Power Company, Denver, the owner recently made a thorough study of the cost of electric cooking for a family of six persons for a period of ten days. Energy was supplied from the commercial circuits of the Denver Gas & Electric Light Company. The range is wound for 220 volt service and has two 10 amp. and three 20 amp. switches controlling corresponding baking and stove circuits. In the table are given the character of meal, materials cooked, maximum demanded in kilowatts, consumption of energy in kw.-hrs. and cost per meal, the data commencing with the installation of the electric range. The cost of electrical energy is figured at 5 cts. per kw.-hr. No previous experience has been had with electric cooking. Records were taken by a pen-recording wattmeter which was care-

TABLE XXII. COST OF ELECTRICAL COOKING

	Breakfast k.w.-hr.	Persons served	Food	Lunch	Persons served	Food	Dinner	Persons served	Food	Special baking	Ironing
Mon.	1.9	5	Cereal, toast, coffee, boiled eggs	1.9	4	Warmed over dishes, tea, toast	1.4	3	Broiled steak, tea, boiled potatoes....	...	...
Tues.	2.8	5	Cereal, coffee, poached eggs, toast	1.5	4	Omelette, tea	3.5	5	Roast mutton, asparagus, potatoes, beets	...	2.9
Wed.	2.8	5	Cereal, coffee, griddle cakes...	0.6	4	Stew, tea	4.9	3	Chops, peas, tea, potatoes, custard....	...	...
Thurs.	1.5	5	Cereal, coffee, toast, boiled eggs	1.6	3	Eggs, tea, toast	6.1	5	Roast veal, corn, spinach, potatoes..	...	...
Fri.	2.5	5	Cereal, coffee, griddle cakes...	2.0	4	Stew, tea, poached eggs	3.7	5	Soup, fried fish, tomatoes, spinach, potatoes, pudding ...	...	...
Sat.	2.6	5	Cereal, coffee, stew, toast	0.5	4	Warmed over soup, tea	3.5	4	Steak, potatoes, corn, baked apples	4.2	...
Sun.	3.1	5	Cereal, coffee, toast, eggs.....	5.0	4	Roast beef, potatoes, string beans, soup, ice cream	0.5	5	Cake (baked Saturday) salad, tea...	...	...
	17.2	35		13.1			23.6			4.2	2.9

Equipment Used

Simplex Range No. 7 consisting of

2-8-in. stoves consuming	1625	watts
1-6-in. stoves consuming	440	"
1-9 by 12-in. broiler consuming	1300	"
1-oven consuming	1500	"
Also 1 plate warmer (12 by 14 by 20) consuming	300	"
Total	5165	"

Consumption Data

Total cooking consumption	51.8	k.w.-hrs.
Watts per person per meal	631	watts
Number of meals served	92	
Average No. persons per meal.....	4.4	
Lighting consumption	5.63	k.w.-hrs.
Milk warmer	1.63	"
Ironing	2.9	"

fully calibrated with an instrument of precision. Much care was taken to keep the range absolutely free from dirt during the progress of the cooking tests.

TABLE XXIII. COST OF ELECTRIC COOKING, FAMILY OF SIX, AT 5 CENTS PER K.W.-HOUR

Meal and materials cooked by electric range	Maximum demand in kilowatts	Kw.-hours required	Cost, cts.
Dinner:			
4.5 lbs. roast lamb, baked white and sweet potatoes, baked rice pudding	2.4	2.7	13.50
Breakfast:			
Oatmeal, baked apples, 8; coffee	2.24	2.5	12.50
Lunch:			
Stewed prunes, tea and potatoes	0.6	0.87	4.35
Dinner	..	...	...
Breakfast:			
Oatmeal, coffee	2.46	1.4	7.00
Lunch:			
Warming potatoes, finnin haddie warmed, tea	2.2	0.65	3.25
Dinner:			
3.5 lbs. veal roast, baked sweet potatoes, 10 baked apples, baked Irish potatoes	2.8	4.35	21.75
Evening:			
Cooking oatmeal	1.0	0.47	2.35
Breakfast:			
Warming oatmeal, coffee	0.68	0.55	2.75
Testing oven, raising temperature from cold to hot	1.4	0.7	3.50
Dinner:			
Stewing 4.5 lbs. chicken, boiled potatoes, toast	2.08	2.0	10.00
Breakfast:			
Baked apples, 8; oatmeal, coffee, baking bread, stewing prunes	2.6	3.20	16.00
Lunch:			
Boiled potatoes, coffee, 3 lbs. pot roast	..	3.15	15.75
Warming coffee, laundress 2 P. M.	0.05	0.1	0.50
Dinner:			
Boiled sweet potatoes, baked potatoes, baked cornbread	2.4	2.75	13.75
Breakfast:			
Baked apples, oatmeal	1.0	0.55	2.75
Dinner:			
Beef stew, carrots, potatoes, prune stew	2.0	2.5	12.50
Breakfast:			
Baked apples, oatmeal	2.48	2.55	12.75
Lunch:			
Warming meat and coffee	1.4	0.7	3.50
Baking 3 loaves graham bread	1.28	1.35	6.75
Dinner:			
Chicken stew, 4.5 lbs.; cranberries, 1 qt.; potatoes boiled (6 large)	1.00	2.15	10.75

Breakfast:			
Baked apples, oatmeal, coffee	2.5	3.25	16.25
Lunch:			
Warming meat and coffee	1.6	0.35	1.75
Dinner:			
Baked finnin haddie, boiled potatoes, baked apple sauce	2.60	3.5	17.50
Breakfast:			
Oatmeal, coffee	0.6	0.6	3.00
Lunch:			
Warming meat, potatoes for yeast	0.90	0.6	3.00
Dinner:			
Meat pie, potatoes boiled	2.2	2.5	12.50
Breakfast:			
Baked apple, oatmeal, coffee	2.5	3.25	16.25
Total	..	49.24	$2.46

Experience showed that some energy was lost by changing from one heat to another in order to regulate the temperature properly. It was found that after the oven was once heated baking could be done at small cost. Roughly the cost of electric cooking varied from 3 to 10 cts. per day per person upon the basis of the above rate per kw.-hr.

Heater Capacities of Simple Devices. (H. O. Swoboda in Electric Journal, July, 1913.)

The heater capacities, given below, are used by the leading American and European manufacturers and represent a fair average of standard practice. The figures indicate the maximum amount of energy required to raise the temperature to the desired point, less energy, of course, being required to maintain this temperature. When two figures are given, both are used, one for slow and one for quick action.

Air Heaters:		
Convectors, smallest size, three heats	600	Watts
Convectors, largest standard size, three heats	18,000	"
Luminous radiators, smallest size, one bulb, single heat	250	"
Luminous radiators, largest standard size, four bulbs, two heats	2,000	"
Quartzalite radiators, smallest size, two heats	600	"
Quartzalite radiators, largest standard size, two heats	1,600	"
Show window convectors, capacity per running yard, single heat	300	"
Street car heaters, smallest unit, three heats	250	"
Street car heaters, largest standard unit, three heats	450	"
Air humidifiers (bronchitis kettles)	600	"
Back rounders, for books, three heats	300	"
Beer vat driers, three heats	3,000	"
Boilers, double (cereal cookers), small size 3 pints, three heats	440	"
Boilers, double, largest standard size 6 quarts, three heats	1,300	"
Boilers, hot water, heaters inside, smallest size 3 gallons, three heats	500	"
Boilers, hot water, heaters inside, largest standard size 100 gals., three heats	14,000	"

Branding irons, single heat ....150 to	660 Watts
Broilers, in open shape, smallest size 16 in. by 14 in., two heats	2,500 "
Broilers, largest standard size, 32 in. by 30 in., two heats	10,000 "
Broilers, open plates, smallest size 8 in. by 7¾ ins., single heat	660 "
Broilers, open plates, largest standard size 39 ins. by 19 ins. two heats	6,400 "
Cauterizing instruments, without loss in controller ....30 to	75 "
Celluloid heaters, three heats	900 "
Chafing dishes, smallest size 2 pints, three heats....	250 "
Chafing dishes, largest standard size 3 pints, three heats	500 "
Chocolate warmers, for maintaining chocolate in a fluid state for dipping, smallest size 12 ins. by 6½ ins. by 5 ins., three heats	220 "
Chocolate warmers, largest standard size, 14¼ ins. by 7⅝ ins. by 6 ins., three heats..................	264 "
Cigar lighters, continuous service, single heat	25 "
Cigar lighters, intermittent service, single heat..75 to	200 "
Circulation water heaters, used in connection with boilers, smallest size, two heats	1,800 "
Circulation water heaters, largest standard size, two heats	3,600 "
Coffee percolators, smallest size 1 pint, single heat ....250 to	400 "
Coffee percolators, largest standard size 4 pints, three heats ....350 to	500 "
Coffee percolators, restaurant size, 12 quarts, single heat	750 "
Coffee roasters, smallest size 2 to 3 lbs., three heats..	800 "
Coffee roasters, largest standard size 8 to 10 lbs., three heats	3,600 "
Coffee urns, smallest size 2 gals., three heats........	1,400 "
Coffee urns, largest standard size 5 gals., three heats	2,500 "
Combs, heated, single heat	50 "
Corn poppers, 1 quart, single heat	300 "
Cooking vessels with covers, smallest size 2 pints, three heats	600 "
Cooking vessels, largest standard size, 26 gals., three heats	7,500 "
Corset irons, 8½ lbs., two heats	500 "
Cosmetic heaters, single heat	25 "
Curling irons, self-containing, single heat..........	20 "
Curling irons, heater in separate tubing, single heat ....60 to	400 "
Dentist's tools, such as root canal driers, guttapercha instruments, bleacher points, wax spatulas, hot air syringes, without loss in controller......6 to	30 "
Disc Stoves, smallest diameter 3 ins., single heat ....100 to	400 "
Disc stoves, largest standard diameter 20 ins., three heats	2,700 "
Distilling apparatus for ether, three heats..........	300 "
Distilling apparatus for water, smallest size 1 quart per hr., single heat	1,000 "
Distilling apparatus, largest standard size 8 quarts per hr., single heat.........................	6,000 "
Domestic flat irons, smallest size 3 lbs., single heat ....200 to	250 "
Domestic flat irons, largest standard size 9 lbs., single heat ....400 to	675 "
Drag irons, smallest size 30 lbs., single heat........	1,400 "
Drag irons, largest standard size 50 lbs., single heat	1,600 "
Egg boilers, smallest size 1 egg, single heat........	200 "

Egg boilers, largest standard size 6 eggs, three heats ....360 to	600 Watts
Finishing (polishing) irons, smallest size 4 lbs., two heats ....250 to	380 "
Finishing (polishing) irons, largest standard size 5½ lbs., two heats	450 "
Fireless cookers ....150 to	660 "
Flask heaters, 8½ ins. diameter, three heats..........	500 "
Flat plates, rectangular or oval, used as food warmers, griddle plates, laboratory plates, glue plates, smallest size 4 by 4 ins., three heats..........	60 "
Flat plates, largest standard size 80 by 40 ins., three heats	4,500 "
Foot warmers, smallest size 9 ins. by 10 ins., single heat	50 "
Foot warmers, largest standard size 10 by 12 ins., three heats	400 "
Frying pans, round, smallest diameter 4 ins., single heat	300 "
Frying pans, largest standard diameter, 12 ins., three heats ....1,800 to	2,000 "
Frying pans, rectangular, with cover, smallest size 10 by 6½ by 5 ins., three heats....................	1,000 "
Frying pans, rectangular, with cover, largest standard size 24 by 12 by 5 ins., three heats..........	3,300 "
Furnaces for dentists, with controller....................	500 "
Furnaces for heat treatment of tool steels and other metallurgical work:	
1 800° F. maximum, smallest size....................	450 "
largest standard size....................	4,150 "
2 000° F. maximum, smallest size....................	650 "
largest standard size....................	15,000 "
3 600° F. maximum, smallest size....................	10,000 "
largest standard size....................	75,000 "
Furnace, Héroult 15-ton steel, with controller....	1,500 Kw.
Furnaces, vacuum type, for laboratory, research work —	
5 cu. in. capacity, 5 600° F. maximum..........	15 Kw.
125 cu. in. capacity, 3 100° F. maximum..........	60 Kw.
Glove form heaters, single heat....................	50 Watts
Glue cookers with circulation water heaters, smallest size 3 gals., three heats	1,800 "
Glue cookers, largest standard size 25 gals., three heats	7,200 "
Glue pots with immersed heaters —	
smallest size ½ pint, three heats....................150 to	330 "
largest standard size 5 gals., three heats..........	2,500 "
Gold annealers for dentists with controller..........	400 "
Goose irons for tailors, smallest size 12 lbs....600 to	770 "
Goose irons, largest standard size 25 lbs..........	825 "
Hat brim irons, single heat	50 "
Hat form heaters, three heats	500 "
Hatters' irons, 9 to 15 lbs., two heats....................	450 "
Heating pads, smallest size 11 by 15 ins., three heats	50 "
Heating pads, largest standard size 24 by 60 ins., three heats	400 "
Hot air blowers, smallest size, two heats..........	500 "
Hot air blowers, largest standard size, two heats..	1,400 "
Hot water cups, smallest size ½ pint, single heat..	150 "
Hot water cups, largest standard size 2 pints, single heat	500 "
Hot water (tea kettles), smallest size 1 pint, single heat ....250 to	300 "
Hot water (tea kettles), largest standard size 2 quarts, three heats	750 "
Hot water pitchers, smallest size 1 quart, single heat	600 "
Hot water pitchers, largest standard size 3 quarts, single heat ....660 to	10,000 "

Hot water tanks for manufacturing purposes, smallest size 26 gals., two heats	4,500 Watts
Hot water tanks, largest standard size 52 gals., two heats	10,000 "
Immersion coils, small size 6½ ins. diameter, three heats	440 "
Immersion coils, largest standard size 11 ins. diameter, three heats	2,500 "
Immersion heaters, cylindrical type, smallest size 2¾ ins. diameter, three heats	300 "
Immersion heaters, cylindrical type, largest standard size 20 ins. diameter, three heats	10,000 "
Immersion disc heaters, smallest size 3 ins. diameter, two heats	150 "
Immersion disc heaters, largest standard size 8 ins. diameter, two heats	660 "
Immersion tube heaters, smallest size, single heat	170 "
Immersion tube heaters, largest standard size, single heat	660 "
Inhaling apparatus, smallest size ½ pint, single heat	100 "
Inhaling apparatus, largest standard size 2½ pints, three heats	800 "
Instantaneous hot water heaters, smallest size ½ pint per min., temperature increase 68° F.	600 "
Instantaneous hot water heaters, largest standard size 10 quarts per minute, temperature increase 136° F.	24,000 "
Ironing machine (mangles), smallest size 40 ins. long, three heats	2,400 "
Ironing machine, largest standard size 80 ins. long, three heats	6,400 "
Lace iron, single heat	70 "
Machine irons for tailors, with controllers, smallest size 12 lbs.	770 "
Machine irons for tailors, with controllers, largest standard size 18 lbs.	770 "
Melting pots for pitch, smallest size 12 ins. diameter, 2½ ins. deep, three heats	1,300 "
Melting pots for pitch, largest standard size 15 ins. diameter, 2½ ins. deep, three heats	1,600 "
Melting pots for sealing wax, paraffine, smallest size ¼ pint, single heat	80 "
Melting pots for sealing wax, paraffine, largest standard size 5 quarts, three heats	550 "
Melting pots for soft metal (lead alloys), smallest size 4 lbs., three heats	200 "
Melting pots for soft metal (lead alloys), largest standard size 50 lbs., three heats	1,500 "
Milk sterilizers for 8 bottles, three heats	700 "
Milk testing sets, single heat	600 "
Milk warmers for 8 ounce bottles ....400 to	500 "
Oil tempering baths, smallest size 9 gals., with controller 600° F. max. temp.	6,000 "
Oil tempering baths, largest standard size 37 gals. with controller 600° F. max. temp.	20,000 "
Ovens for baking, roasting, drying, warming, enameling, smallest size 14 by 14 by 18 ins., three heats	200 "
Ovens for baking, roasting, drying, warming, enameling, largest standard size, 42 by 30 by 67 ins., three heats	10,000 "
Potato cookers, smallest size 5 quarts, three heats	750 "
Potato cookers, largest standard size 10 quarts, three heats	1,000 "
Potato steamers for hotels, smallest size 20 quarts, six heats	3,000 "
Potato steamers for hotels, largest standard size 50 quarts, six heats	4,500 "
Puff irons, smallest size 3 by ¼ ins., three heats	155 "

Puff irons, largest standard size 6 by 3½ ins., three heats	400 Watts
Ranges for domestic and restaurant use, 2 to 6 persons	4,000 "
Ranges for domestic and restaurant use, 6 to 12 persons	5,500 "
Ranges for domestic and restaurant use, 12 to 20 persons	7,500 "
Sand box heaters for trolley cars, single heat	100 "
Sealing wax heaters, hand tool style, single heat	75 "
Shoe irons, portable, single handle, six heats	100 "
Shoe irons, portable, double handle, six heats	210 "
Shoe relasting irons, portable, single heat	50 "
Shoe warmers, smallest size 4 ins. by 1¾ ins. by ½ ins. single heat	20 "
Shoe warmers, largest standard size 8 ins. by 3 ins. by 1 in., single heat	.30 "
Sleeve irons, 3½ lbs., two heats	300 "
Soldering irons, smallest size 10 ounces, single heat	75 "
Soldering irons, largest standard size 4½ lbs., single heat	450 "
Steam sterilizers, small size 5 quarts, three heats	3,500 "
Steam sterilizers, large size 6 quarts, three heats	4,000 "
Sterilizers for surgical and dental instruments, smallest size 8 ins. by 3½ ins. by 2 ins., three heats	350 "
Sterilizers for surgical and dental instruments, largest standard size, 24 ins. by 6 ins. by 4 ins., three heats ..1 400 to	1,800 "
Sweating blankets, 60 ins. by 18 ins., with controller	800 "
Toaster stoves domestic, portable type, single heat ..400 to	600 "
Toaster stoves, restaurant type, single heat.1 500 to	3,000 "
Towel dryers, three heats	600 "
Waffle irons, each section, single heat	385 "
Welding machines, smallest sizes	1,000 "
Welding machines, largest sizes	150,000 "

Electric Current Required for Heating Water: (Engineering Magazine, August, 1914.)

Radiation losses are based on 2 ins. of asbestos or magnesia lagging.

No radiation losses from the pipes of the connecting system have been included in these calculations.

Computations are made at 100 per cent. efficiency, so that due allowance should be made to suit the conditions present in each application.

Electrically Heated Devices in the Printing Shop of P. F. Collier & Son, New York. From Foster's Electrical Engineer's Pocket Book.)

Apparatus	Type and size	Max. amp.	Min. amp.	Volts	Watts
2 glue pots	Simplex, 20 gals.	100	22	110	22,000
23 " "	Hadaway, 1 qt.	2	.5	"	5,060
1 " "	Simplex, 1 qt.	2.5		"	275
8 " "	Hadaway, 2 qts.	10	2.5	"	8,800
2 " "	Hadaway, 2 gals.	22.8		220	12,672
2 wax heaters		100	40	110	22,000
5 press heads	22 ins. by 24 ins. by 3⅞ ins.	35	2.8	"	19,250
1 " "	" " " " " " " "	36	4	"	3,960
1 " "	" " " " " " " "	36	3.6	"	3,960
1 " "	" " " " " " " "	36	3.5	"	3,960
1 " "	" " " " " " " "	36	4.5	"	3,960

Apparatus			Type and size								Max. amp.	Min. amp.	Volts	Watts
1	"	"	19	"	" 12	"	"	"	"	"	30	2.5	"	3,300
1	"	"	12	"	"	"	"	"	"	"	25	2.5	"	2,750
49														111,947

Laboratory Use of Electric Heating Devices. The milk supply of New York City is governed by tests made in the Laboratory of the Board of Health, by means of electric stoves. Twenty-five 4-in. disc stoves, of 60 watts capacity, are used to boil the ether used in the tests. Fourteen times per hour these little stoves cause the ether to vaporize. The germ producer, measuring 22 by 22 by 22 ins., is heated to 130° C., by means of electricity, a maximum current of 16 amp. being employed for 15 mins. every hour, while 3

TABLE XXV. ELECTRIC CURRENT REQUIRED FOR HEATING WATER

Tank, capacity, gal.	Tank length, feet	Tank diameter, in.	Water contents, lbs.	Watts radiation loss per hour, tem. diff. 100 deg.	Watts input to raise metal tank 100 deg. in 1 hour.	Watts input to raise water only, 100 deg. in 1 hour.	Total kw. input required to supply radiation losses and raise temperatures of tank and water from 60 deg. to 160 deg. in 1 hour	2 hours	3 hours	5 hours
12	3	10	100	125.	158.	2,920.	3.14	1.60	1.08	.678
17	2.8	12	142	154.	193.	4,140.	4.41	2.24	1.52	.944
18	3	12	150	161.	201.	4,380.	4.66	2.37	1.61	.996
21	3.5	12	175	183.	229.	5,120.	5.44	2.77	1.87	1.162
24	4	12	200	205.	253.	5,840.	6.20	3.15	2.13	1.321
28	3.5	14	233	220.	285.	6,820.	7.22	3.66	2.48	1.531
30	3	16	250	227.	317.	7,310.	7.74	3.93	2.66	1.638
32	4	14	267	249.	324.	7,790.	8.24	4.18	2.83	1.748
35	5	13	292	278.	348.	8,520.	9.00	4.57	3.10	1.913
36	4.5	14	300	271.	359.	8,770.	9.26	4.70	3.18	1.961
40	5	14	333	300.	377.	9,730.	10.26	5.21	3.52	2.17
42	4	16	350	286.	412.	10,220.	10.77	5.46	3.69	2.27
48	6	14	400	352.	465.	11,680.	12.32	6.25	4.23	2.61
53	4	18	442	330.	522.	12,900.	13.59	6.88	4.64	2.85
63	6	15	525	411.	705.	15,330.	16.24	8.22	5.55	3.41
66	5	18	550	396.	880.	16,050.	17.13	8.66	5.84	3.58
79	6	18	658	468.	915.	19,210.	20.36	10.36	6.94	4.26
82	5	20	684	447.	968.	19,940.	21.13	10.65	7.19	4.41
85	5	20	708	447.	1,020.	20,680.	21.92	11.07	7.46	4.56
100	5	22	834	498.	1,056.	24,330.	25.64	12.94	8.71	5.33
120	5	24	1,000	557.	1,232.	29,200.	30.71	15.49	10.42	6.36
140	6	24	1,168	645.	1,408.	34,300.	36.03	18.18	12.22	7.46
150	4	30	1,250	608.	1,480.	36,510.	38.39	19.30	12.97	7.90
168	7	24	1,400	740.	1,654.	40,880.	42.90	21.64	14.55	8.88
180	5	30	1,500	712.	1,690.	43,800.	45.85	23.10	15.52	9.45
192	8	24	1,600	828.	1,900.	46,720.	49.16	24.79	16.66	10.26
220	6	30	1,835	835.	2,025.	53,290.	55.61	28.01	18.81	11.46
250	7	30	2,082	953.	2,110.	60,830.	63.42	31.95	21.46	13.06
295	8	30	2,460	1,062.	2,325.	71,780.	74.64	37.58	25.23	15.35
315	6	36	2,626	1,033.	3,415.	76,650.	80.58	40.55	27.20	16.43
365	7	36	3,044	1,172.	3,800.	88,820.	93.21	46.90	31.46	19.11
420	8	36	3,500	1,312.	3,170.	102,200.	106.00	52.85	35.12	20.93
430	6	42	3,588	1,246.	3,134.	105,200.	108.96	54.79	36.74	22.30
500	7	42	4,172	1,415.	3,520.	122,300.	126.53	62.62	42.65	25.87

amps. keep up the desired temperature. The cocoa and coffee trade has applied electric heat to its small desiccating or drying cabinets. A dryer 3.5 by 5 ft., requiring a temperature of 150 degrees, requires about 74 watts per cu. ft. when properly jacketed. The beans are particularly susceptible to the odors arising from combustion, hence the advantage of electric heat. For drying kilns 40 watts per cu. ft. are recommended.

Candy Manufacture. Warming tables and chocolate dipping-pots have proved successful. 50 watts produce sufficient heat to keep the chocolate in working condition. A 30-gal. tank holding caramel paste is supplied with 10 kw.-hrs. to keep the paste at 285° C., and each melting costs about 65 cts. The service is intermittent, hence the adaptability of electric heat.

Soldering and Branding Irons. The canning industry, as well as the makers of switchboards, and others, find the electric soldering iron a useful and economical tool. It has been found more economical to operate electric soldering irons heated by current costing 5 cts. per kw.-hr. than irons heated in gas furnaces, with gas at $1.00 per 1000 cu. ft. Heaters of 110-watt capacity are made, into which a soldering iron is thrust, thereby doing away with the connecting handle cord. One thousand hogs per hour are stamped "Inspected" by the government meat inspectors in Chicago, by means of a 400-watt branding tool, which is an electric soldering iron with a die inserted instead of the copper tip.

Thawing Water Pipes. The following figures show the details of operation of a 44-cell storage battery outfit, mounted on an automobile truck, in comparison with those obtained by the use of a rheostat in series with a d.c. 3 wire Edison system with the neutral wire grounded. The figures represent the average amounts in each case.

	Amperes	K.w. hours	Time, mins.	Pipe, inch.	Voltage	Cost per case	Revenue per case
Storage battery ..	513	1.39	5.44	⅝	31.5	$10.85	$16.40
Street supply	275	10.4	19.0	⅝	120.0	14.43	16.93

The street supply is used until the season has so far advanced that the number of cases will warrant the exclusive service of an automobile truck.

Power Required for Electric Thawing of Frozen Mains:

TABLE XXVI. DATA ON THE AMOUNT OF CURRENT AND THE LENGTH OF TIME REQUIRED TO THAW FROZEN WATER PIPES BY ELECTRICITY

Size pipe (iron) * inches	Length feet	Volts	Amperes	Time required to thaw, min.	Kw.-hr.
¾	40	50	300	8	2
¾	100	55	135	10	1.24
¾	250	50	400	20	6.67
1	250	50	500	20	8.33
				Hours	
1	700	55	175	5	48.1
4	1,300	55	260	3	42.9
10	800	62	400	2	49.6

* Add 50% to amperage for thawing lead pipe.

Cost of Operating Electrically Heated Utensils. (From Foster's Electrical Engineer's Pocket Book.)

Article	Average watt hour consumption	Period of operation, min.	Cost during that period at 10 cts. per kw.-hr., cts.
Chafing dish	400	20	1.33
Pint baby milk warmer and food heater	250	6	1.25
Quart food heater	500	6	0.50
Coffee percolator	300	20	1.00
Stove, 6 ins.	500	15	1.25
Stove, 8 ins.	800	15	2.00
Boiler 9 by 12 ins.	1200	15	3.00
Curling iron heater	60	15	0.15
Iron, 3½ lbs.	250	30	1.25
Iron, 6 lbs.	500	30	2.50
Frying pan (7 ins. diameter)	500	30	2.50
Waffle iron	500	12	1.00
Tea kettle	300	20	1.00
Glue pot, 1 qt.	300	20	1.00
Soldering iron, 2 lb.	200	30	1.00
Doctor's sterilizer	1000	30	5.00
Bate's room radiator	1000	30	5.00
Heating pad	50	per hr.	0.50

The Power Consumption of Domestic Heating Devices Electrically Operated and their Cost of Operation per Hour on a Basis of 10c. per kw.-hr. for Electricity:

	Watts	Cents
Broilers, 3 ht.	300 to 1200	3 to 12
Chafing dishes, 3 ht.	200 to 500	2 to 5
Cigar lighters	75	0.75
Coffee percolators for 6 in. stove	100 to 440	1 to 4.4
Coil heaters	110 to 440	1.1 to 4.4
Corn popper	300	3
Curling-iron heaters	60	0.6
Double boilers, 6 in., 3 ht. stove	100 to 440	1 to 4.4
Flatiron (domestic size) 3 lbs.	275	2.75
Flatiron (domestic size) 4 lbs.	350	3.5
Flatiron (domestic size) 5 lbs.	400	4
Flatiron (domestic size) 6 lbs.	475	4.75
Flatiron (domestic size) 7.5 lbs.	540	5.4
Flatiron (domestic size) 9 lbs.	610	6.1
Foot warmers	50 to 400	0.5 to 4
Frying kettles, 8 in. diameter	825	8.25
Griddle cake cookers, 9 by 12 ins., 3 ht.	330 to 880	3.3 to 8.8
Griddle-cake cookers, 12 by 18 ins., 3 ht.	500 to 1500	5 to 15
Heating pads	50	0.5
Instantaneous flow water heaters	2000	20
Kitchenettes (complete), average	1500	15
Nursery milk warmers	450	4.5
Ornamental stoves	250 to 500	2.5 to 5
Ovens	1200 to 1500	12 to 15
Plate warmers	300	3
Radiators	700 to 6000	7 to 60
Ranges: 3 heats, 4 to 6 people	1000 to 4515	10 to 44
Ranges: 3 heats, 6 to 12 people	1100 to 5250	11 to 52
Ranges: 3 heats, 12 to 20 people	2000 to 7200	20 to 72
Shaving mugs	150 to	1.5
Stoves (plain), 4.5 in., 3 ht.	50 to 220	0.5 to 2.2
Stoves (plain), 6 in., 3 ht.	100 to 440	4.4
Stoves (plain), 7 in., 3 ht.	120 to 600	1.2 to 6

	Watts	Cents
Stove (plain), 8 in., 3 ht.	165 to 825	1.5 to 8.25
Stoves (plain), 10 in., 3 ht.............	275 to 1100	2.6 to 11
Stoves (plain), 12 in., 3 ht.............	325 to 1300	3.2 to 13
Stove, traveler's	200	2
Toasters, 9 in. by 12 in., 3 ht..........	330 to 880	3.2 to 8.8
Toasters, 12 in. by 18 in., 3 ht.	500 to 1500	5 to 15
Urns, 1-gal., 3 ht.	110 to 440	1 to 4.4
Urns, 2-gal., 3 ht.	220 to 660	2.2 to 6.6
Urns, 3-gal., 3 ht.	330 to 1320	2.6 to 13.2
Urns, 5-gal., 3 ht.	400 to 1700	4 to 17
Waffle irons, 2 waffles	770	7.5
Waffle irons, 3 waffles	1150	11.5

An Electric Heater for Thawing Eplosives was used at the Roosevelt drainage tunnel in Cripple Creek, Colo., says the Engineering Record, May 15, 1909. It consists of two 12 in. by 24 in. rectangular frames made of 1.5 in. by .25 in. iron, held apart 3 ins. vertically and supported on legs above the floor. Telephone insulators spaced on 1.5 in. centers are placed around the sides of each frame, and between each corresponding pair of insulators ordinary coils of galvanized telephone wire are strung, all the sets of wires being connected in series. The coils are heated by the electric lighting current, and in about 30 minutes warm the small powder house, 4 ft. by 5 ft. in ground plan and 6 ft. high, to a temperature of 80 deg. F. The cost of this method of heating is about 10 cts. per 24 hrs. and is said to be far more economical than if coal were used for fuel.

Cost of Electric Heating in Shoe Factory. (Electrical World, March 31, 1917.) In this establishment thirteen machines are provided with electric heat, and in the eight months ended Feb. 28, 1917, the total energy consumption for this service was 19,600 kw.-hrs., the number of pairs of shoes manufactured being 118,359. The average energy required per 100 pairs of shoes was about 16.55 kw.-hrs. The energy consumption of the several machines for heating service was as follows in the months of maximum and minimum shoe production:

	August, 1916		November, 1916	
Number pairs manufactured	16,998 kw.-hr.		12,490 kw.-hr.	
	Total	Per 100 pairs	Total	Per 100 pairs
Two Goodyear stitchers	369	2.2	348	2.8
Two Goodyear welters	232	1.4	192	1.5
Two pulling-over machines ...	616	3.6	83	0.7
Four box toe machines.......	724	4.3	700	5.6
One bottom drier	741	4.4	638	5.1
One bottom filler	211	1.2	178	1.4
One Gem insole machine	72	0.4	43	0.4
	2965	17.5	2182	17.5

It will be noticed that while the energy per 100 pairs of shoes is apparently a constant, except for the pulling-over machines, the energy consumed is much less for quantity production. For manufacturing or other reasons the energy consumption of the pulling-over machines was much greater in August than in the following November.

Proving the Economy of Electric Cooking. (Electrical World, Aug. 19, 1916.) Figures recently secured on the cost of operating twenty-nine electric ranges in the Boulevard Court Apartments, Detroit, Mich., give 2 kw.-hrs. per day as the average consumption for cooking for families of two and three persons. In the same apartments the use of electrical energy for purposes other than cooking averaged a trifle above 5 kw.-hr. per day during the period of observation. In only one instance was it apparent that the electric range was not being used regularly, the consumption in the other twenty-eight cases varying from a minimum daily consumption of 0.44 kw.-hr. to a maximum of 4.4 kw.-hrs. per day.

TABLE XXVII. FIGURES ON CONSUMPTION AND COST OF ELECTRIC COOKING BY TWENTY-NINE ELECTRIC RANGE USERS, BOULEVARD APARTMENTS, DETROIT

Apartment	No. of days	Kw.-hr. consumed by range	Monthly cost for operating range
First floor:			
1	63	167	$3.18
2	52	23	.54
3	59	55	1.12
4	48	107	2.86
5	63	160	3.05
8	35	137	4.71
Second floor:			
1	62	77	1.50
2	50	108	2.59
3	62	98	1.90
4	60	117	2.34
5	63	119	2.27
6	30	90	3.60
7	37	26	.76
8	62	159	3.08
Third floor:			
1	59	63	1.28
3	60	265	5.30
4	..	...	...
5	45	80	2.27
6	60	57	1.19
7	48	44	1.11
8	45	112	2.99
Fourth floor:			
1	59	98	2.14
4	63	171	3.26
5	62	201	3.90
6	62	168	3.25
7	63	99	1.89
8	62	196	3.79
Basement:			
5	35	53	1.80
7	35	2	.06
Front	50	69	1.96
29	1554 days	3121	$2.40
Average	53.6 days	2 per day 60 per month	

The ranges installed are a recent model, the feature of which is the compartment (or fireless) cooker. This cooker is set into the body of the stove so that its cover when closed is flush with the cooking surface and is flanked on either side by a hot plate. The oven is of the elevated type with a glass door. An automatic clock mechanism operates a master switch and pilot lamp, this feature being designed to prevent the circuit being left "on" through forgetfulness upon the part of the operator.

A study of the subjoined data will reveal several interesting facts. It is not apparent, for example, that more than one of the active users of the cooking service was extravagant in that service alone. In all cases but one where the total monthly bills were above $5, the energy used otherwise than in the range amounts to approximately 30% of the total, whereas the average of the entire twenty-nine apartments shows that about 25%, in round figures, was used for light and purposes other than cooking.

Another interesting fact is that in 1554 range-days, the consumption averaged only 2 kw.-hrs. per day, although this record was for the experimental period when it is commonly expected that the consumption will be high owing to the housewives' unfamiliarity with the electric stoves.

Power Cost of Ironing in a Domestic Laundry. We have taken the following from Foster's Electrical Engineer's Pocket Book.

An average family of five persons, where the collars and cuffs are sent out to be ironed, consumes about 13.2 kw.-hrs per month for ironing, which at 10 cts. per kw.-hr. amounts to $1.32 per month, which is about the same as if gas were used, costing $1.00 per 1000 cu. ft. The cost of operation varies with size of iron. For ordinary domestic requirements, without a current regulator, the iron most commonly used weighs about 6 lbs. and consumes about 500 watts per hr. The regulators, whether of the switch in the handle or resistance in the stand type, effect a saving of from 15 to 20%. The power consumption of the various types of irons follows:

	Watts
4 lbs. Troy polishing, diamond face	330
3½ " small seaming (can be connected to lamp socket)	200
4 " gentleman's small hat iron	200
5½ " light domestic	500
5½ " light domestic, round wire	500
7 " domestic	600
5½ " Morocco bottom	500
Morocco bottom, round wire	500

Flatirons. The American Handbook for Electrical Engineers gives the following: An internally heated gas flatiron of household size burns about 5 cu. ft. of gas per hr. For continuous service with an externally-heated iron three irons are required, two heating while one is being used; for such service about 16 cu. ft. of gas are used per hr. by the burner. An electric flatiron of household size takes about 550 watts. Hence, assuming gas to cost $1.00 per 1000 cu. ft. and electricity to cost 10 cts. per kw.-hr. the energy cost per hr. for each of the three types would be:

Internally-heated gas flatiron	0.5
Externally-heated gas flatiron	1.6
Electric flatiron	5.5

However, the evident advantages of cleanliness, convenience, safety and comfort bring about a very extensive use of the electric flatiron, even though the actual cost is greater than for coal or gas heating.

In figuring the cost of operation of the electric iron, in the above abstract, no allowance has been made for the fact that the better grades of irons will hold their heat a remarkably long time. It is not necessary to have the current turned on continuously but once the iron is hot the current may be turned off and on and a considerable saving be effected.

Cost of Disc and Propeller Fans. Disc Fans are extensively used wherever large volumes of air are to be moved at low velocity, and where the resistance to be overcome is slight. This type is not suitable for forcing air against pressure, a condition which requires a cased fan. The efficiency of the disc type decreases rapidly as the resistance increases, but when the removal of air from rooms does not require conducting pipes, the low first cost, the smooth-running qualities, and the durability of this type of fan are readily appreciated. Disc fans are especially adapted to the ventilation of kitchens, restaurants, engine rooms, work shops, and offices, and the removal of vapors in industrial establishments, and in laundries, dye houses, drying rooms, etc.

In case of wear or accident any part may be immediately replaced, for they are made on the interchangeable plan. The Disc Fan consists of a substantial hub, into which are cast radial steel arms having steel-plate blades attached thereto. These blades, placed at an angle to the direction of flow, force the air in lines parallel to the shaft. To obtain movement of air in the opposite direction it is only necessary to reverse the angle of the blades

TABLE XXVIII. DISC AND PROPELLOR FANS

Diam. of fan in ins.	Minimum r.r.m.	Weight in lbs., propeller fan	Weight in lbs., disc fan	Net price * propeller fan
18	550	60	100	$24.00
24	400	125	130	30.00
30	325	160	165	39.00
36	275	225	190	48.00
42	235	400	290	60.00
48	200	465	350	72.00
54	175	600	425	90.00
60	165	675	535	110.00
66	150	720	685	132.00
72	135	950	875	150.00
78	127	1050	1000	165.00
84	120	1125	1025	180.00
96	100	1375	1175	210.00
108	90	1700	1470	240.00
120	80	2000	1800	300.00

* The above net prices are for propeller fans; for the disc fans subtract 20% from same.

or change the direction of rotation. The wheel revolves within a substantial circular frame, carrying two self-oiling bearings, and having a pulley on the shaft.

TABLE XXIX. STEEL PRESSURE BLOWERS

FOR FOUNDRY WORK

Number of blower	Diam. of outlet in ins.	R.p.m. for ½ lb. pressure	Weight in lbs.	Net price
4/0	2¾	7,782	17	$13.50
2/0	3½	6,023	35	18.00
0	4	5,112	55	23.40
1	4⅞	4,486	85	32.40
2	5⅜	3,774	110	39.60
3	6¼	3,233	155	49.50
4	7⅜	2,818	315	63.00
5	8⅞	2,416	375	81.00
6	10¼	2,198	475	103.50
7	12	1,773	840	162.00
8	13⅞	1,548	1125	202.50
9	16	1,332	1650	292.50
10	18½	1,169	2650	405.00

TABLE XXX. BLOWERS AND EXHAUSTERS

Number of blower or exh'ter	Outside diam. of inlet of exh'ter in ins.	Outside diam. of outlet in ins.	Weight in lbs.		Net price
			Blower	Exh'ter	
4/0	3⅝	2¾	15	20	$10.80
2/0	4⅞	4⅛	30	40	13.50
0	5¾	4¾	52	58	18.00
1	6½	5¾	80	90	23.40
2	7½	7½	120	123	29.70
3	9	9	190	200	39.60
4	10½	10⅝	265	300	49.50
5	12¼	12¼	380	400	63.00
6	15	14⅝	525	590	81.00
7	16⅝	16⅝	925	1030	135.00
8	18⅝	18¾	1340	1555	180.00
9	21½	21¾	1975	2100	225.00
10	24½	24⅝	2550	2700	292.00

The above blowers and exhausters are regularly built with bottom horizontal discharge in all sizes, and with up blast discharge in sizes 3 to 10, inclusive. Either blowers or exhausters can be made down blast or top horizontal discharge when so ordered. The weights given do not include packing and are for bottom horizontal discharge.

TABLE XXXI. FOUNDRY TABLE FOR STEEL PRESSURE BLOWERS

Number of blower	Cu. ft. of air per min.	Pressure in wind box ozs. per sq. in.
2	500	7
4	1,000	7
5	1,500	8
6	2,000	9

Number of blower	Cu. ft. of air per min.	Pressure in wind box ozs. per sq. in.
7	2,500	9
7	3,000	10
7	3,500	10
8	4,000	11
8	4,500	11
8	5,000	12
9	5,500	12
9	6,000	13
9	6,500	12
9	7,000	13
9	7,500	14
10	8,000	12
10	8,500	13
10	9,000	14
10	9,500	12
10	10.000	13
10	10,500	14
10	11,000	13
10	11,500	14
10	12,000	15
10	12,500	16

To find number or size of blower to supply air for the required capacity of a cupola, take 500 cu. ft. of air per minute at the given pressure to melt one ton of iron per hour.

Table XXXII gives the number of revolutions necessary to produce the given pressure at the fan outlet when its area is within the capacity of the blower. Owing to losses due to transmission, this pressure cannot be maintained at any more or less distant point, such as the wind box of a cupola or the tuyere pipe of a forge, unless the speed of the fan is increased sufficiently to produce an excess of pressure equal to the transmission loss.

Cost of Heating and Ventilating Systems. (D. D. Kimball in the School Board Journal, abstracted in the Heating and Ventilating Magazine, March, 1915.) A study of the cost of installation of heating and ventilating plants, made in a number of schools, showed that the prevailing custom of apportioning a certain percentage of the total cost of the building for the installation of the heating and ventilating plant is of no value, as these percentage ratios vary more than 100%, even with similar classes of installations. For a given size of building, the cost of the heating and ventilating systems will be approximately the same whether the building is a monumental stone structure or a plain wooden structure, but the percentage of cost of the system will be very different.

Classification of Systems. As a result of this study, the following scheme of classification has been arrived at:

Class A. Plants providing for fire-tube boilers, double fan systems, air washers and humidifiers, individual or double duct systems and modulating control of direct radiators and mixing dampers.

Class B. Same as Class A, but using automatic stokers and water-tube boilers instead of fire-tube boilers.

Class C. Same as Class A, but eliminating the modulation control of radiators and dampers and using the single trunk ducts.

TABLE XXXII. REVOLUTIONS OF STEEL PRESSURE BLOWER NECESSARY TO MAINTAIN A GIVEN PRESSURE OVER AN AREA WHICH IS WITHIN THE CAPACITY OF THE BLOWER

No. of blower	Pressure, in ozs. per sq. in. 4	5	6	7	8	9	10	11	12	13	14	15	16
4/0	5548	6190	6767	7294	7782	8237	8665	....	....	....	....	....	....
2/0	4294	4792	5238	5645	6023	6375	6706	7019	....	....	....	....	....
0	3645	4067	4446	4792	5112	5412	5692	5958	6210	....	....	....	....
1	3199	3569	3901	4205	4486	4749	4995	5229	5450	....	....	....	....
2	2691	3002	3282	3537	3774	3995	4202	4398	4595	4762	....	....	....
3	2305	2572	2811	3030	3233	3422	3599	3768	3927	4079	....	....	....
4	2009	2242	2451	2642	2818	2983	3138	3285	3424	3556	....	....	....
5	1722	1922	2101	2264	2416	2557	2690	2815	2935	3048	3157	....	....
6	1567	1749	1912	2061	2198	2327	2448	2562	2670	2774	2866	....	....
7	1264	1410	1542	1662	1773	1877	1974	2066	2154	2237	2316	2393	2467
8	1104	1232	1346	1451	1548	1639	1720	1804	1880	1953	2023	2089	2154
9	950	1060	1159	1249	1332	1410	1487	1553	1618	1681	1741	1799	1854
10	834	930	1017	1096	1169	1238	1302	1363	1420	1475	1528	1579	1627

Class D. Same as Class C, except that it eliminates the use of air washers and humidification systems.

Class E. All other systems.

Manifestly there are many combinations of equipment which render an exact determination of classification difficult, but in general this classification has proven satisfactory.

After a careful study of this method of classification and the figures on costs as thus obtained, it was found that the only satisfactory basis of determining the cost of the installation of the heating and ventilating plant was on the basis of the cubic feet of space in the building. The variation in costs within the different classes of systems is rarely over 10% from the average, the greatest variation occurring in Class A. The resulting costs are as follows:

Class A, cost of plant per cu. ft., 2.7 cts. to 3.3 cts.— average 3.1 cts.

Class B, cost of plant per cu. ft. 3.3 cts. to 3.8 cts.— average 3.4 cts.

Class C, cost of plant per cu. ft. 2.2 cts. to 2.5 cts.— average 2.4 cts.

Class D, cost of plant per cu. ft. 2.2 cts. to 2.3 cts.— average 2.25 cts.

Class E, cost of plant per cu. ft. 1.9 cts. to 2.3 cts.— average 2.1 cts.

If classes D and E were but abandoned and a proper amount of skill were used in the design, installation and operation of the remaining classes, a sufficient appropriation being provided for the installation and operation of the ventilating plant, it is believed that little basis would be left for complaint as to the success of the artificial ventilating system.

As a matter of information it is interesting to note that the cost of plumbing equipment for school buildings ranges from three-quarters of a cent to one and one-half cents per cubic foot, the average being one and one-tenths cents. The cost of electrical equipment, exclusive of electric power plants, ranges from one-half to one ct. per cu. ft., the average being seven-tenths per cu. ft.

In the case of the heating and ventilating, plumbing and electrical work, the costs seem to be approximately the same in grade schools and high schools.

Operating Cost Heating and Ventilating Plants. (H. M. Hart in Domestic Engineering, Nov. 1, 1913.)

Residence Heating. Method of computing cost of operation. For this example we will take a room requiring 100 sq. ft. of direct steam radiation to maintain a temperature of 70 deg. when the outside temperature is 10 deg. below zero.

The maximum difference in temperature is — 10 deg. to 70 deg. = 80 deg. The average difference in temperature is 35 deg. to 70 deg = 35 deg., which, theoretically, would mean that the radiator would be in use 35/80 or 43.75 per cent. of the time.

Taking the heating season as seven months, or 5,040 hours, 43.75 per cent. of this time would be 2,205 hours, the theoretical number of hours that radiation would be in use. The average radiator gives off approximately 225 B.t.u. per sq. ft. per hr. Therefore, the total B.t.u. per season would be estimated as follows:

$$225 \times 100 \times 2{,}205 = 49{,}612{,}500.$$

The average B.t.u. available per pound of anthracite coal is estimated at 8,000; therefore, $49{,}612{,}500 \div 8{,}000 = 6{,}201$ lbs. of coal, or 3.1 tons per sq. ft. of radiation.

The average indirect steam radiator gives off approximately 450 B.t.u. per square foot per hour. As it requires approximately 50% more radiation for indirect heating than direct heating, this would mean that it would take $\dfrac{450 \times 150}{8{,}000 \times 2{,}000} \times 2{,}205 = 9.3$ tons, to heat the same room with indirect radiation.

In order to see how this checked up in actual practice, the actual fuel consumption in 10 residences was obtained from the owners, and the results given in table XXXIII.

TABLE XXXIII. FUEL CONSUMPTION IN TEN RESIDENCES

	Bank fires at night	Automatic control on boilers	System	Sq. ft. direct steam equivalent	Sq. ft. indirect steam equivalent	Estimated consumption in tons	Actual consumption in tons
1	Yes	No	Steam	666	1,080	88	55
2	No	No	Water	1,350	1,800	148	60
3	Yes	Yes	Water	1,720	....	53½	40
4	No	No	Water	1,535	86	53	35
5	No	Yes	Water	1,340	730	86	45
6	Yes	No	Water	1,050	384	56	30
7	No	Yes	Water	1,215	312	57	40
8	Yes	Yes	Steam	1,296	384	64	45
9	No	Yes	Steam	878	2,100	157	70
10	No	Yes	Water	1,335	240	56	36

School Buildings. The difficulty of securing any exact figures is apparent when we take into consideration the hours which these plants operate. Again, there are vacations cutting into the period of operation. If we assume 172 days of 8 hours each with an average temperature of 38 deg. and a temperature of heated air in the chambers at 120 deg. the figures agree fairly with actual coal burned. The figures given are for an entirely different class of buildings, yet it will be seen that the quantity of coal per cu. ft. of air heated per season was close. What it would do in a large number of buildings we are not prepared to say.

Spalding School: Air per hr., 1,147,440 cu. ft.; blower, 72 by 42 in.; boiler, firebox, 720 sq. ft.; amount small egg average 106 tons, at $7 per ton, per season, 0.18 lb. coal per season per ft. of air warmed.

Twenty-eight room buildings, 4,162,729 cu. ft. per hr.; bituminous coal, 400 tons at $2.95 per ton; 0.19 lb. coal per season per ft. of air warmed.

Rosehill School — Air per hour, 800,000 cu. ft.; horse-power motor, 5; amount small egg, 73 tons at $7 per ton; 0.18 lb. coal per season per ft. of air warmed.

Cost of Manufacture in Distilled-Water Ice Plants. (Peter Neff in Power, Nov. 25, 1913.)

In general the manufacturing cost of ice per ton in any plant is the total amount expended during the year in its production divided by the number of tons of ice sold. Ideas as to what items are a legitimate charge will vary somewhat, but to my mind they are: Depreciation, repairs, insurance and taxes, labor, fuel and sundries (oil, waste, ammonia, salt, etc.).

The first three of these items may be termed the fixed charge. They are not dependent on the output, run over the entire year, and may even be greater when the plant is not producing. They are a large factor in the cost of production, and are often partially or totally omitted when thinking of the cost. The last three have a direct relationship to the output, and are the ones usually taken into account.

For the sake of convenience the output for 330 days was taken as a year's production, as all plants should have a period of shutdown for overhauling. Then three periods, varying by 50 days, viz., 280, 230 and 180, were taken as representing productive periods. This division is purely arbitrary, and has been used simply for convenience, but serves to cover the various productive periods as found in ice plants. While the computations herewith are based on ammonia-compression plants, in view of the fact that all the distilled water comes from the boilers they will apply equally well to absorption and to plants where other than ammonia is used for the refrigerant.

The value of the land on which the plant is located is not taken into account, but must be considered and added to the figures here given to arrive at the total investment. It is further assumed that there is no charge for water, but that it is pumped by steam power, and this steam is part of that taken from the boilers for distilled water.

Fixed Charges. To obtain the cost of the buildings, dimensions as given by two of the manufacturing companies were taken, and the cost based on 8 cts. per cu. ft. of space inclosed. Nothing has been provided but the necessary equipment, and there will be variations in this item, but not sufficient to seriously affect the results. These two items give what is termed the investment.

Depreciation is that ordinarily adopted, viz., 6 per cent., which will return the cost of the investment in practically 17 years. This has been used both for the buildings and the equipment.

For repairs the 5% employed has been arrived at from the experience of others in various lines of manufacturing, and form a study of widely scattered ice plants. The 4% for taxes and insurance seemed to be a fair average.

TABLE XXXIV. INVESTMENT AND FIXED CHARGE IN DOLLARS FOR STANDARD DISTILLED-WATER ICE PLANTS

Daily capacity of plant in tons	10	15	20	25	30	35	40	50	60	80	100
Buildings	4,000	5,000	6,000	6,700	8,000	9,500	10,500	11,500	12,500	15,500	19,000
Equipment	8,000	11,000	13,000	16,000	18,000	22,000	25,000	29,000	32,000	42,000	56,000
Investment	12,000	16,000	19,000	22,700	26,000	31,500	35,500	40,500	44,500	57,500	75,000
Fixed charges *	1,800	2,400	2,850	3,405	3,900	4,725	5,325	6,075	6,675	8,625	11,250

* Composed of 6 per cent. depreciation, 5% repairs, 4% insurance and taxes.

TABLE XXXV. TONS OF ICE PRODUCED AND FIXED CHARGE PER TON IN DOLLARS

Daily capacity of plant in tons	10	15	20	25	30	35	40	50	60	80	100
Tonnage — 180 days.	1,800	2,700	3,600	4,500	5,400	6,300	7,200	9,000	10,800	14,400	18,000
Charge per ton	1.00	0.89	0.79	0.76	0.72	0.75	0.74	0.68	0.62	0.60	0.63
Tonnage — 230 days.	2,300	3,450	4,600	5,750	6,900	8,050	9,200	11,500	13,800	18,400	23,000
Charge per ton	0.78	0.70	0.62	0.59	0.57	0.59	0.58	0.53	0.48	0.47	0.49
Tonnage — 280 days.	2,800	4,200	5,600	7,000	8,400	9,800	11,200	14,000	16,800	22,400	28,000
Charge per ton.....	0.64	0.57	0.51	0.49	0.47	0.48	0.48	0.43	0.40	0.39	0.40
Tonnage — 330 days.	3,300	4,950	6,600	8,250	9,900	11,550	13,200	16,500	19,800	26,400	33,000
Charge per ton	0.55	0.49	0.43	0.41	0.39	0.41	0.40	0.37	0.34	0.33	0.34

TABLE XXXVI. COST OF LABOR FOR STANDARD DISTILLED-WATER ICE PLANTS

Daily capacity of plant in tons	10	15	20	25	30	40	50	60	80	100
Tankmen	3.50	3.50	4.00	4.00	4.00	4.00	4.00	4.00	4.00	8.00
Engineers	4.50	5.50	5.50	5.50	5.50	6.00	7.50	7.50	7.50	7.50
Firemen	...	...	3.50	4.00	4.00	4.00	4.00	4.00	6.00	8.00
Oilers	...	...	...	...	...	2.00	2.00	2.00	2.00	4.00
Housemen	...	...	...	...	...	...	...	4.00	4.00	4.00
Extra men	...	...	...	...	...	1.50	2.00	2.00	2.00	4.00
Net total	8.00	9.00	13.00	13.50	13.50	17.50	19.50	23.50	25.50	35.50
10 per cent.	0.80	0.90	1.30	1.35	1.35	1.75	1.95	2.35	2.55	3.55
Total daily	8.80	9.90	14.30	14.85	14.85	19.25	21.45	25.85	28.05	39.05
Labor per ton	0.88	0.66	0.72	0.60	0.50	0.48	0.43	0.43	0.35	0.39

TABLE XXXVII. MANUFACTURING COST OF ICE PER TON AND AMOUNT OF ICE PRODUCED

Daily capacity of plant in tons	0	15	20	25	30	35	40	50	60	80	100
180 days' production											
Fuel	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Sundries	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Labor	0.88	0.66	0.72	0.60	0.50	0.49	0.48	0.43	0.43	0.35	0.39
Fixed charge	1.00	0.89	0.79	0.76	0.72	0.75	0.74	0.68	0.62	0.60	0.63
Total cost per ton	2.62	2.29	2.25	2.10	1.96	1.98	1.96	1.85	1.79	1.69	1.76
Tonnage for period	1,800	2,700	3,600	4,500	5,400	6,300	7,200	9,000	10,800	14,400	18,000
230 days production											
Fuel, sundries, labor	1.62	1.40	1.46	1.34	1.24	1.23	1.22	1.17	1.17	1.09	1.13
Fixed charge	0.78	0.70	0.62	0.59	0.57	0.59	0.58	0.53	0.48	0.47	0.49
Total cost per ton	2.40	2.10	2.08	1.93	1.81	1.82	1.80	1.70	1.65	1.56	1.62
Tonnage for period	2,300	3,450	4,600	5,750	6,900	8,050	9,200	11,500	13,800	18,400	23,000
280 days production											
Fuel, sundries, labor	1.62	1.40	1.46	1.34	1.24	1.23	1.22	1.17	1.17	1.09	1.13
Fixed charge	0.64	0.57	0.51	0.49	0.47	0.48	0.48	0.43	0.40	0.39	0.40
Total cost per ton	2.26	1.97	1.97	1.83	1.71	1.71	1.70	1.60	1.57	1.48	1.53
Tonnage for period	2,800	4,200	5,600	7,000	8,400	9,800	11,200	14,000	16,800	22,400	28,000
330 days production											
Fuel, sundries, labor	1.62	1.40	1.46	1.34	1.24	1.23	1.22	1.17	1.17	1.09	1.13
Fixed charge	0.55	0.49	0.43	0.41	0.39	0.41	0.40	0.37	0.34	0.33	0.34
Total cost per ton	2.17	1.89	1.89	1.75	1.63	1.64	1.62	1.54	1.51	1.42	1.47
Tonnage for period	3,300	4,950	6,600	8,250	9,900	11,550	13,200	16,500	19,800	26,400	33,000

The three foregoing items constitute what is termed the fixed charge. Table XXXV shows how this affects the cost of the ice under the different periods of production, and is obtained by dividing 15 per cent. of the investment by the tonnage for the period indicated, the result being the charge per ton for that period.

Operating Cost. 10 per cent. is added to cover nonproductive time due to stopping and starting and incidental shutdowns.

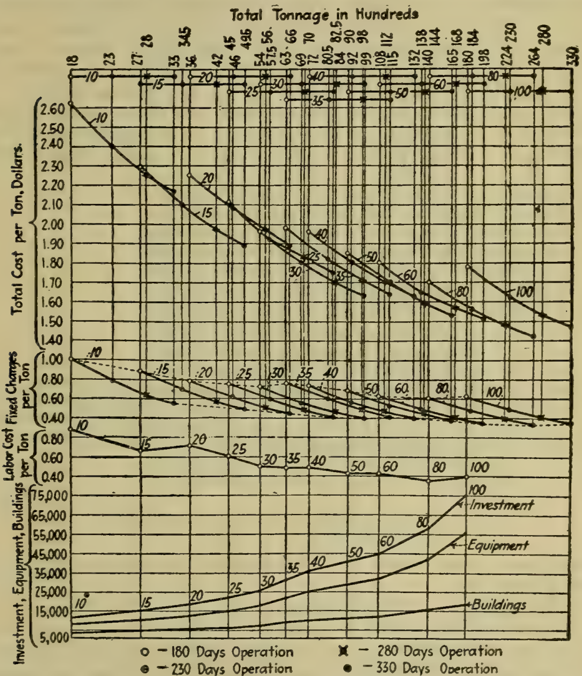


Fig. 7. Manufacturing cost per ton in standard distilled-water ice plants.

The fuel was difficult to decide upon, but here as elsewhere, average conditions are taken. The boiler evaporation was taken at 6 to 1 and the losses between the boilers and the ice cans as 20%. For nonproductive periods 10% was also added. The price of coal is taken at \$3 per ton of 2000 lbs. A change of 50 cts. per ton in the cost of fuel makes 11 cts. difference in the cost of the ice per ton.

Sundries is also an uncertain item, but the 8 cts. per ton has been found to check with practical results.

Total Cost per Ton of Ice. In Fig. 7 some interesting things are to be noticed. In the matter of fixed charges there is a group from the 20 to the 50 tons that shows a wide variation. This condition is also shown in the grouping of the plant productions as brought out at the top of the chart, and clearly indicates that there are too many different sizes of plants to cover the range of production. If, now the 25-, 35- and 40-ton plants are eliminated, it is seen that the diagram would be more regular, and that the 20-, 30- and 50-ton plants cover the range even better than the intermediate sizes named. In the labor curve there is a pronounced rise at the 20-ton plant, but this is due more than anything else to the drop from the 10- to the 15-ton plant. If the 15-, 25- and 40-ton plants are omitted, the labor curve from the 20-ton on is decreasing, until the 80-ton is reached, where it is at a minimum, rising again toward the 100-ton plant. The total cost

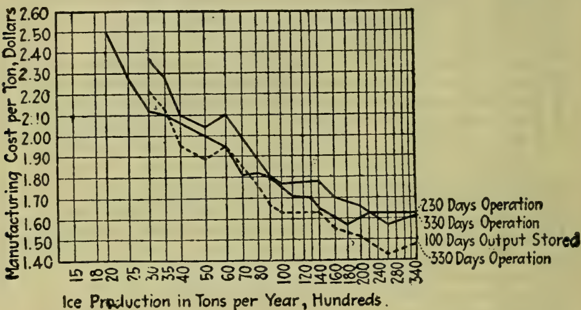


Fig. 8. Total cost of ice per ton.

curves show that when all is considered the 80-ton plant is the most economical.

In the standard distilled-water plants under consideration, it is fair to assume that there is sufficient refrigerating capacity to care for an ice-storage house, and that the steam used for this purpose will not increase the boiler load. In the event that the house is located away from the plant, or has an individual refrigerating equipment, it will practically double the cost of storage as here given.

A properly built ice storage will be a substantial affair, and the depreciation will not be as heavy as on a manufacturing plant; 5% will cover this as well as the repairs. The initial cost may be taken at $5 per ton of storage capacity, and the size will be determined by allowing 50 cu. ft. per ton of ice stored. Where possible the dimensions should be such as to give a maximum content with a minimum of wall surface. For handling the ice an allowance of 15 cts. per ton is made and to cover incidentals another 10 cts. per ton is added. Table XXXVIII has been derived

TABLE XXXVIII. AMOUNT PER TON TO BE ADDED FOR ICE STORAGE TO MANUFACTURING COST FOR 330-DAY PERIOD

Daily Capacity of Plant in Tons	Tons of Ice Stored												
	1000	1500	2000	2500	3000	3500	4000	5000	6000	7000	8000	9000	10,000
10	0.15												
15	0.10	0.15											
20	0.07	0.11	0.15										
25	0.06	0.09	0.12	0.15									
30	0.05	0.075	0.10	0.125	0.15								
35	0.04+	0.06	0.09	0.11—	0.13	0.15							
40	0.04—	0.05	0.075	0.095	0.11	0.13	0.15						
50	0.03	0.045	0.06	0.075	0.09	0.105	0.12	0.15					
60	0.025	0.04—	0.05+	0.06	0.07	0.09	0.10	0.125	0.15				
80	0.02—	0.03	0.04	0.05	0.055	0.06	0.07	0.09	0.11	0.13	0.15		
100	0.015	0.02	0.03	0.04	0.045	0.05	0.06	0.075	0.09	0.105	0.12	0.135	0.15

from the foregoing data in this way: The number of tons stored is taken at 50 cts. per ton, and this amount divided by the total tonnage for a 330-day period, as shown in Table XXXVII, gives the amount that is to be added.

It will be noticed that this has been carried only to the point where the amount to be added in all cases is substantially 15 cts., which represents a storage period of 100 days' output.

From the cost of production, shown in Table XXXVII, it is evident that anyone operating a plant full capacity for 230 days can, if they have sale for the ice, increase the capacity 43.5% with practically no change in the cost per ton, by using storage for 100 days' output and operating 330 days.

This statement, however, may be misleading, for this increased tonnage could be got with a larger plant in the 230-day period for less per ton. This is brought out in Figs. 8 and 9. This exempli-

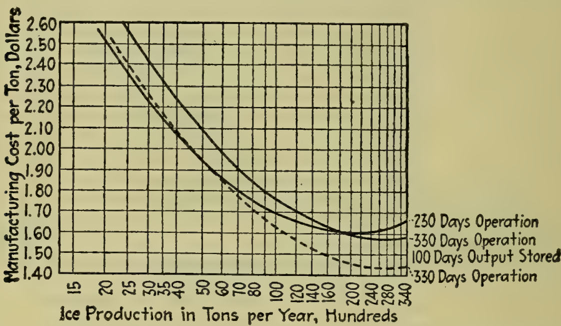


Fig. 9. Approximate cost of ice per ton deduced from Fig. 8.

fies what has already been stated that conditions must be studied and given due consideration in determining what is best in a particular case.

Often there are considerations such as varying demands at particular times of the year that will more than compensate for the extra charge of storing. These figures show, however, that the storage can be used to advantage in increasing the output where the plant is ordinarily shut down part of the time, and that there is not a great deal of difference in cost whether storage is used with the plant operating longer or a larger plant for a shorter period of time. On the other hand, the having of a supply of ice on hand may be the means of largely increasing the revenue and is therefore desirable.

Initial and Operating Costs of Refrigeration Plants. (Robert P. Kehoe in Power, May 25 and Oct. 19, 1915.)

The following tables will be found useful by operators and owners interested in refrigerating and ice-making plants of com-

TABLE XXXIX. COMPARISON OF INITIAL INVESTMENT, DAILY AND YEARLY COSTS OF OPERATION OF REFRIGERATING PLANTS, WITH DIFFERENT KINDS OF MOTIVE POWER

Refrigerating capacity in tons per day of 24 hours	10			15		
Kind of power	Steam	Electric motor	Oil engine	Steam	Electric motor	Oil engine
Investment for complete mechanical equipment of refrigerating plant	$5000.00	$4500.00	$5300.00	$7000.00	$6400.00	$7400.00
Daily operating expense:						
Labor during night and day (assuming that engineers, etc., are also required for other purposes)	2.00	1.50	1.50	3.00	2.00	2.00
Fuel:						
Coal at $3.50 per ton; oil at 3½ cts. per gal.; current at 2 cts. per kw.-hr.	3.50	4.80	1.50	4.75	7.20	1.80
Ammonia, oil, waste and supplies	0.75	0.75	0.75	1.00	1.00	1.00
Net operating expense per day	$6.25	$7.05	$3.75	$8.75	$10.20	$4.80
Daily operating expense for 60% of year at full capacity	1350.00	1523.00	810.00	1889.00	2204.00	1037.00
Full labor expense for balance of year	288.00	216.00	216.00	432.00	288.00	288.00
10% of investment to cover depreciation, repairs and incidentals	500.00	450.00	530.00	700.00	640.00	740.00
Total annual expense	$2138.00	$2189.00	$1556.00	$3021.00	$3132.00	$2055.00
Total expense per ton of refrigeration per day	$1.00	$1.00	$0.72	$0.93	$0.96	$0.64

TABLE XXXIX.—*Continued.*

Refrigerating capacity in tons per day of 24 hours	20			25		
Kind of power	Steam	Electric motor	Oil engine	Steam	Electric motor	Oil engine
Investment for complete mechanical equipment of refrigerating plant	$8000.00	$7300.00	$8400.00	$9200.00	$8400.00	$9500.00
Daily operating expense:						
Labor during night and day (assuming that engineers, etc., are also required for other purposes)	3.50	2.50	2.50	4.00	3.00	3.00
Fuel:						
Coal at $3.50 per ton; oil at 3½ cts. per gal.; current at 2 cts. per kw.-hr.	6.00	9.60	2.20	7.00	12.00	2.50
Ammonia, oil, waste and supplies	1.25	1.25	1.25	1.50	1.50	1.50
Net operating expense per day	$10.75	$13.35	$5.95	$12.50	$16.50	$7.00
Daily operating expense for 60% of year at full capacity	2322.00	2884.00	1286.00	2700.00	3564.00	1512.00
Full labor expense for balance of year	504.00	360.00	360.00	576.00	432.00	432.00
10% of investment to cover depreciation, repairs and incidentals	800.00	730.00	840.00	920.00	840.00	950.00
Total annual expense	$3626.00	$3974.00	$2486.00	$4196.00	$4836.00	$2894.00
Total expense per ton of refrigeration per day	$0.84	$0.92	$0.58	$0.78	$0.89	$0.54

paratively small capacity. No particular application has been considered and the data may be used for any of the branches of refrigeration, such as general cold storage, markets, hotels, apartment houses, water-cooling plants, fur storage, drygoods stores, and hospitals.

The estimated first costs are necessarily approximate. A refrigerating equipment for a hotel will cost more than a refrigerating plant used solely for cooling water. Again, the same size plant in one hotel may cost more than in another. The figures are a good average and the comparison between the costs of plants with different drive is quite correct.

Those who now operate plants and know what their equipment cost can use the table to advantage in adding or deducting to the same extent as indicated in the table to determine the difference in cost of other methods of drive. Then by applying the actual costs of labor and fuel, which are known, in the same manner, it may be ascertained how economically each plant is performing and if improvement is possible.

Refrigerating plants of from ten to twenty-five tons' daily capacity are seldom operated by men engaged to do nothing else, but usually by men required for operating other machinery. This has been considered in the table. The figures may be easily corrected to suit local conditions, and the price of fuel also regulated to correspond. The table represents a fair average.

The 60% yearly load factor assumed should be close to actual conditions in the majority of plants. It will be noted that the labor charge has been carried through the whole year. The 10% added for depreciation and repairs can be divided about half and half. A 5% yearly depreciation means complete renewal in fifteen years if the 5% is calculated as a sinking fund; 5% yearly for repairs and incidentals should be ample. No building has been taken into consideration because small refrigerating plants are usually located in some part of an existing building.

The advantage of making calculations of operating costs on a yearly basis cannot be doubted. In fact, the daily operating expense alone is misleading, particularly when the yearly load factor is low and a comparatively short period of operation must bear the depreciation and upkeep expense for the year.

The total cost per ton of refrigeration per day is interesting when compared to the cost of using ice for the same purpose. Ice is seldom delivered for less than \$2.50 to \$3 per ton, even in large quantities, and often the price is \$3 to \$4. The table proves that much saving can be accomplished by the refrigerating plant, without considering greater convenience, elimination of slop from melting ice and better preservation of perishable goods under lower temperatures.

The economy of oil engines as compared with ordinary steam plants and electric motors using central-station current at average rates is quite evident. In the smaller sizes of refrigerating and ice-making plants considered in the tables, the cheaper cost of operation is even more pronounced because small steam plants are

TABLE XL. COMPARISON OF INITIAL INVESTMENT, DAILY AND YEARLY COST OF OPERATION OF ICE PLANTS, WITH DIFFERENT KINDS OF MOTIVE POWER

Capacity in Tons of Ice per Day of 24 Hours	10			15		
Kind of Power / Type of Plant	Steam, Distilled Water	Electric motor, Raw Water	Oil engine, Raw Water	Steam, Distilled Water	Electric motor, Raw Water	Oil engine, Raw Water
Investment:						
Mechanical equipment complete	$8,500.00	$7,500.00	$8,500.00	$11,500.00	$10,000.00	$11,500.00
Building	3,500.00	3,000.00	3,000.00	4,500.00	4,000.00	4,000.00
Total investment (excluding land)	$12,000.00	$10,500.00	$11,500.00	$16,000.00	$14,000.00	$15,500.00
Daily operating expense:						
One day engineer	3.00	3.00	3.00	3.00	3.00	3.00
One night engineer	2.50	2.50	2.50	2.50	2.50	2.50
One day tankman	2.00	2.00	2.00	2.00	2.00	2.00
One night tankman	....	....	....	2.00	2.00	2.00
Extra labor	....	....	....	....	....	....
Fuel: Coal at $3.50 per ton; oil at 3½ cts. per gal.; current at 2 cents per kw.-hr.	7.00	12.00	2.63	10.00	18.00	3.94
Ammonia, oil, waste and supplies	1.50	1.50	1.50	2.25	2.25	2.25
Net operating expense per day	$16.00	$21.00	$11.63	$21.75	$29.75	$15.69
Yearly Summary — 50 Per Cent. Load Factor (6 Months' Full Operation)						
Daily operating expense during period of full operation, in dollars	$2,880.00	$3,780.00	$2,094.00	$3,915.00	$5,355.00	$2,825.00
Half of labor expense for balance of year	675.00	675.00	675.00	855.00	855.00	855.00
Fixed charges:						
5% depreciation on cost of equipment	425.00	375.00	425.00	575.00	500.00	575.00
3% depreciation on building	105.00	90.00	90.00	135.00	120.00	120.00
5% total investment for repairs, taxes, water and incidentals	600.00	525.00	575.00	800.00	700.00	775.00
Total annual expense	$4,685.00	$5,445.00	$3,859.00	$6,280.00	$7,530.00	$5,150.00
Number of tons ice produced annually	1,800.00	1,800.00	1,800.00	2,700.00	2,700.00	2,700.00
Total cost per ton of ice per annum	2.60	3.03	2.15	2.33	2.79	1.91
Average selling price to make 10 per cent. on investment	3.26	3.60	2.79	2.93	3.31	2.48

TABLE XL — *Continued.*

Capacity in Tons of Ice per Day of 24 Hours	20			25		
Kind of Power / Type of Plant	Steam, Distilled Water	Electric motor, Raw Water	Oil engine, Raw Water	Steam, Distilled Water	Electric motor, Raw Water	Oil engine, Raw Water
Investment:						
Mechanical equipment complete	$12,500.00	$11,000.00	$12,500.00	$15,000.00	$13,300.00	$15,000.00
Building	5,500.00	5,000.00	5,000.00	6,500.00	6,000.00	6,000.00
Total investment (excluding land)	$18,000.00	$16,000.00	$17,500.00	$21,500.00	$19,300.00	$21,000.00
Daily operating expense:						
One day engineer	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50
One night engineer	2.50	2.50	2.50	3.00	3.00	3.00
One day tankman	2.00	2.00	2.00	2.00	2.00	2.00
One night tankman	2.00	2.00	2.00	2.00	2.00	2.00
Extra labor	....	....	....	2.00	....	....
Fuel: Coal at $3.50 per ton; oil at 3½ cts. per gal.; current at 2 cts. per kw.-hr.	13.00	23.00	5.25	15.50	30.00	6.56
Ammonia, oil, waste and supplies	3.00	3.00	3.00	3.75	3.75	3.75
Net operating expense per day	$26.00	$37.00	$18.25	$31.75	$44.25	$20.81
Yearly Summary — 50 Per Cent. Load Factor (6 Months' Full Operation)						
Daily operating expense during period of full operation, in dollars	$4,680.00	$6,660.00	$3,285.00	$5,715.00	$7,965.00	$3,746.00
Half of labor expense for balance of year	900.00	900.00	900.00	1,125.00	945.00	945.00
Fixed charges:						
5% depreciation on cost of equipment	625.00	550.00	625.00	750.00	665.00	750.00
3% depreciation on building	165.00	150.00	150.00	195.00	180.00	180.00
5% total investment for repairs, taxes, water and incidentals	900.00	800.00	875.00	1,075.00	965.00	1,050.00
Total annual expense	$7,270.00	$9,060.00	$5,835.00	$8,860.00	$10,720.00	$6,671.00
Number of tons ice produced annually	3,600.00	3,600.00	3,600.00	4,500.00	4,500.00	4,500.00
Total cost per ton of ice per annum	2.02	2.52	1.62	1.97	2.38	1.48
Average selling price to make 10 per cent. on investment	2.52	2.97	2.08	2.45	2.81	1.96

not usually economical, while small oil engines perform almost as well as large units.

It may not always be advisable to install an oil engine, on account of local conditions which may favor a steam engine or electric motor. Steam may be required for other purposes. Sometimes the power plant may have to be located in such close quarters that only an electric motor can be used to preserve sanitary conditions. Sometimes it would be inadvisable to place an oil engine or a steam unit in the crowded basement of a hotel, restaurant or hospital where other work is going on and perhaps where foodstuffs are handled. But if the location and requirements do not favor other power, the oil engine will afford a marked saving in the yearly expense.

The table which refers to ice plants is arranged on a basis similar to the table for refrigerating plants. The cost of a special building is included, and the labor is calculated to be used for the ice plant alone. Only half the labor is included during the balance of each year when the plant is shut down or not operated at full capacity. Moreover, special tabulations are given for different yearly load factors. The importance of this factor is indicated by the wide difference in cost of production. For example the 25-ton oil-engine-driven plant shows a total producing cost of $3.27 per ton when the yearly output is equivalent to three months' full operation while the same plants producing the equivalent of seven months' full operation reduce the cost per ton to $1.82.

Large Ice Plants. Table XLI offers an opportunity to study the relations between the three principal types of plants in five sizes, ranging from 100 to 500 tons' capacity per day of 24 hrs. The steam engines are compound condensing.

No consideration is given to cost of property, which of course will vary with the location. If desirable, an amount to cover this item may be added to the investment in each case in order to figure the percentage of possible profit. This will have no effect on the operating cost unless interest is added in the estimate of yearly expense. In this event the interest on the total amount of borrowed money may be figured in. At any rate the comparisons are true, and if the cost of labor and that of fuel are adjusted to suit a particular locality, the table will be a correct guide in the determination of the advantageous kind of plant to install.

The usual refinements advisable for large distilled-water plants have been covered in the first costs of the steam-driven plants. These refinements include evaporators and automatic stokers. An average economy of nine tons of ice per ton of coal has been assumed. This may be increased to ten or more tons per ton of coal under ideal conditions, but the usual working basis will probably not average more than nine to one.

In the raw-water plants the standard drop-tube system is the basis. This may be either the multiple or double drop-tube type according to the latest practice in uptodate successful installations. If a fine quality of ice is required, the Beals system may be added, in which case the first cost and the depreciation will increase, but

TABLE XLI. INVESTMENT, DAILY AND YEARLY COST OF OPERATION OF LARGE ICE PLANTS

Capacity in tons of ice per 24 hr	100 Tons			200 Tons		
Type of plant (all 300 lb. cans), water	Distilled	Raw water		Distilled	Raw water	
Motive power	Steam engines	Electric motors	Oil engines	Steam engines	Electric motors	Oil engines
Investment:						
Mechanical equipment complete	$62,000	$52,000	$70,000	$119,000	$99,000	$135,000
Building	37,500	35,000	35,000	65,000	60,000	60,000
Total investment (excluding land)	$99,500	$87,000	$105,000	$184,000	$159,000	$195,00
Daily Operating Expense:						
Chief engineer	$6.00	$5.00	$6.00	$7.00	$6.00	$7.00
Assistant engineers (1)	3.50	3.50	3.50	(1) 4.00	4.00	4.00
Oilers (2)	4.00	4.00	4.00	(2) 4.00	4.00	4.00
Firemen (2)	4.00	...	...	(2) 4.50	...	...
Tankmen (4)	8.00	(6) 12.00	12.00	(8) 16.00	(12) 24.00	24.00
Storehousemen (2)	4.00	4.00	4.00	(2) 4.00	4.00	4.00
Other labor	...	...	...	(2) 4.00	(1) 2.00	2.00
Fuel, coal at $3.50 per ton, oil at 3½ cts. per gal., current at 1 ct. per kw-hr.	38.50	60.00	15.00	77.00	120.00	30.00
Ammonia, oil, waste, etc.	10.00	10.00	10.00	18.00	18.00	18.00
Net operating expense per day	$78.00	$98.50	$54.50	$138.50	$182.00	$93.00
Total cost of operation per year on basis of operating full capacity 4 months, one-half capacity 4 months and one-quarter capacity 4 months, equivalent to full operation for 216 days (60 per cent. load factor).						
Operating cost of equivalent of 216 days of full operation	$16,848	$21,276	$11,772	$28,670	$39,312	$20,088
All labor expense for balance of year	4,248	4,104	4,248	6,264	6,336	6,192
Five per cent. depreciation on cost of mechanical equipment	3,100	2,600	3,500	5,950	4,950	6,750
Three per cent. depreciation on cost of building	1,125	1,050	1,050	1,950	1,800	1,800
Five per cent. on total investment for repairs, taxes, water and incidentals	4,975	4,350	5,250	9,200	7,950	9,750
Total annual expense	$30,296	$33,380	$25,820	$52,034	$60,348	$44,580
Number tons ice produced annually	21,600	21,600	21,600	43,200	43,200	43,200
Total cost per ton of ice per annum	$1.40	$1.55	$1.19	$1.21	$1.40	$1.03

TABLE XLI.—*Continued.*

Capacity in tons of ice per 24 hr.	300 Tons			400 Tons		
Type of plant (all 300-lb. cans), water	Distilled	Raw water		Distilled	Raw water	
Motive power	Steam engines	Electric motors	Oil engines	Steam engines	Electric motors	Oil engines
Investment:						
Mechanical equipment complete	$171.000	$141,000	$195,000	$218,000	$178,000	$250.000
Building	95,000	88,000	88,000	120,000	111,000	111,000
Total investment (excluding land)	$266,000	$229,000	$283,000	$338,000	$289,000	$361,000
Daily Operating Expense:						
Chief engineer	$7.50	$6.50	$7.50	$8.00	$7.00	$8.00
Assistant engineers (1)	(2) 7.00	7.00	7.00	(2) 8.00	8.00	8.00
Oilers (2)	(4) 8.00	8.00	8.00	(4) 8.00	8.00	8.00
Firemen (2)	(2) 5.00	...	...	(2) 6.00	...	...
Tankmen (4)	(10) 20.00	(15) 30.00	(15) 30.00	(14) 28.00	(21) 42.00	42.00
Storehousemen (2)	(2) 4.00	4.00	4.00	(4) 8.00	8.00	8.00
Other labor	(3) 6.00	(1) 2.00	2.00	(3) 6.00	(1) 2.00	2.00
Fuel, coal at $3.50 per ton, oil at 3½ cts. per gal., current at 1 ct. per kw.-hr.	115.50	180.00	45.00	154.00	240.00	60.00
Ammonia, oil, waste, etc.	25.00	25.00	25.00	31.00	31.00	31.00
Net operating expense per day	$198.00	$262.50	$128.50	$257.00	$346.00	$167.00

Total cost of operation per year on basis of operating full capacity 4 months, one-half capacity 4 months and one-quarter capacity 4 months, equivalent to full operation for 216 days (60 per cent. load factor).

Operating cost of equivalent of 216 days of full operation	$42,768	$56,700	$27,756	$55,512	$74,736	$36,072
All labor expense for balance of year	8,280	8,280	8,424	10,368	10,800	10,944
Five per cent. depreciation on cost of mechanical equipment	8,550	7,050	9,750	10,900	8,900	12,500
Three per cent. depreciation on cost of building	2,850	2,640	2,640	3,600	3,330	3,330
Five per cent. on total investment for repairs, taxes, water and incidentals	13,300	11,450	14,150	16,900	14,450	18,050
Total annual expense	$75,740	$86,120	$62,720	$97,280	$112,216	$80,996
Number tons ice produced annually	64,800	64,800	64,800	86,400	86,400	86,400
Total cost per ton of ice per annum	$1.17	$1.33	$0.97	$1.13	$1.30	$0.94

TABLE XLI.—*Continued.*

Capacity in tons of ice per 24 hr.	500 tons		
Type of plant (all 300-lb. cans), water	Distilled	Raw water	
Motive power	Steam engines	Electric motors	Oil engines
Investment:			
Mechanical equipment complete	$260,000	$210,000	$300,000
Building	150,000	140,000	140,000
Total investment (excluding land)	$410,000	$350.000	$440,000
Daily Operating Expense:			
Chief engineer	$9.00	$8.00	$9.00
Assistant engineers (1)	(2) 10.00	10.00	10.00
Oilers (2)	(4) 8.00	8.00	8.00
Firemen (2)	(2) 7.00	....	....
Tankmen (4)	(16) 32.00	(24) 48.00	48.00
Storehousemen (2)	(4) 8.00	8.00	8.00
Other labor	(4) 8.00	(2) 4.00	4.00
Fuel, coal at $3.50 per ton, oil at 3½ cts. per gal., current at 1 ct. per kw.-hr.	192.50	300.00	75.00
Ammonia, oil, waste, etc.	36.00	36.00	36.00
Net operating expense per day	$310.50	$422.00	$198.00
Total cost of operation per year on basis of operating full capacity 4 months, one-half capacity 4 months and one-quarter capacity 4 months, equivalent to full operation for 216 days (60 per cent. load factor).			
Operating cost of equivalent of 216 days of full operation	$67,068	$91,152	$42,768
All labor expense for balance of year	11,808	12,384	12,528
Five per cent. depreciation on cost of mechanical equipment	13,000	10,500	15,000
Three per cent. depreciation on cost of building	4,500	4,200	4,200
Five per cent. on total investment for repairs, taxes, water and incidentals	20,500	17,500	22,000
Total annual expense	108,000	108,000	108,000
Number tons ice produced annually	$116,876	$135,736	$96,496
Total cost per ton of ice per annum	$1.08	$1.26	$0.90

the labor cost will be reduced. The Beals process requires no more labor than the regular distilled-water system, while in drop-tube plants the tubes have to be watched and the core water replaced at the proper time.

The product of drop-tube systems with properly filtered water is always good, unless water of unusual characteristics is used. The refilled core water, which is frozen without agitation, produces a core similar to distilled-water ice. The slight odor which can often be detected in the latter when broken up is rarely found in raw-water ice. The Beals system considerably reduces the core, which makes almost the entire block transparent.

Raw-water ice is surely gaining in favor, and operators are also perfecting the method for handling these plants to such a degree that no trouble is now experienced in turning out a first-class marketable product. The installation of plants of 400 and 200 tons' daily capacity in New York City marks the final stage in the universal approval of this process. As both plants are driven by oil engines, the success of this type of motive power for ice manufacture is also indicated. There are now many oil-engine-driven plants of all sizes.

The price of oil has been taken as 3.5 cts per gal. In many sections a lower price is obtainable. It is advisable to adopt a type and make of engine that will burn the heaviest and cheapest grades of fuel oil.

A 1 ct. rate per kw.-hr. for electric current is used because any higher price could not be considered. Even this figure does not compare favorably with either the oil-engine or steam plant. The claim is often made that the power consumption in such plants is less than 50 kw.-hr. per ton of ice; but the average electric-driven plant will be found to use nearly 60. As all the other figures in the table are made conservatively to represent everyday conditions, 60 kw.-hr. per ton of ice is quite appropriate.

The yearly load factor of 60% is equivalent to 216 days of full operation. This would mean about four months of full operation, four months at half capacity and four months at one-quarter capacity. In large plants in cities of considerable size these conditions usually exist.

Reproduction Cost of a 65-Ton Ice Plant. The data in Table XLII are taken from one of our appraisals of a public utility property (in the South) of which the ice plant was operated as an auxiliary. The compressors for this plant were housed in the buildings of the main plant and were run on steam from the main boilers.

Mechanical Refrigeration Gives a Timely Load. The cost of electric energy for operating a 5-ton plant for a butcher shop at special refrigeration rates is given in Electrical World, April 28, 1917.

Mechanical refrigeration offers opportunities as a central station load in many different ways, from the small plant of the householder to the large plants of hotels, and including coldstorage plants for provisions and furs and for butcher shops and other stores.

TABLE XLII. GENERAL SUMMARY OF THE ESTIMATED COST OF REPRODUCTION

		Reproduction cost new
1.	Buildings	$13,600
2.	Ice making machinery	49,483
3.	Miscellaneous equipment	109
4.	Supplies and material on hand	519
		$63,711
5.	Engineering and management, 10% items 1 to 4 inc.	6,371
		$70,082
6.	Legal 1½% items 1 to 5 inc.	1,061
		$71,143
7.	Interest during construction 5% items 1 to 6	3,557
	Total	$74,700

TABLE XLIII. DETAILED ESTIMATED COST OF REPRODUCTION OF PROPERTY

1. BUILDINGS

Description	Total cost
Refrigeration plant buildings, freezing room, ice storage room and beer vaults, including foundations of tanks and machinery and all insulation	$13,200
Ice chute to dock	400
	$13,600

2. ICE MAKING MACHINERY

Ammonia Compressors	
Ammonia compressor 15 by 30 in. driven by 17 by 42 in. heavy duty corliss engine, complete including high pressure side connections together with steam condenser, coolers, coke filter, charcoal filter, cold water tank, pump and connections	$11,500
Ammonia compressor 15 by 30 in. driven by 14 by 26 by 56 in. tandem compound corliss engine, complete including high pressure side connections	8,970
Freezing Tanks	
40 ton ice tank, flooded system, 26 by 76 by 4 ft., containing 665–300 lb. cans (11½ by 22½ ins. at top by 44 ins. deep), freezing coils, liquid gas headers, brine propeller driven by 7.5 h.p. motor; traveling ice crane, automatic sprinkler and hose, together with all suction and liquid piping and fittings, completely installed	11,350
25 ton ice tank, flooded system, 13 ft. 9 ins. by 76 ft. 4 ins., containing 350–300 lb. cans (11½ by 22½ ins. at top by 44 ins. deep) freezing coils, liquid and gas headers, brine propeller driven by 5 h.p. motor, traveling ice crane with pneumatic hoist, automatic sprinkler and hose; together with all suction and liquid piping and fittings, completely installed; also two automatic recording ice chutes, each for two-300 lb. cakes	6,235
Ammonia Condensers	
2 12 coil atmospheric ammonia condensers with all connections at $2,530	5,060
Miscellaneous	
Westinghouse air compressor 8 by 8 by 10 ins., reservoir and connections, together with 1 pneumatic hoist	460
Ammonia regenerator with connections	300

Description	Total cost
Ice Making Machinery	
50 ton vacuum reboiling apparatus with exhaust steam separator, pump and connection	$ 1,150
36 by 36 ins. vacuum reboiling apparatus complete with float, and 4 by 5 by 5 ins., single high vacuum pump	575
2 in. centrifugal brine circulating pump, driven by 5 h.p. motor	145
Motor driven ice saw	375
Motor driven endless chain ice hoist	400
Piping installed and lagged	2,963
	$49,483

TABLE XLIV. COST OF OPERATING 10 H.P. MOTOR FOR BUTCHER SHOP REFRIGERATION

Month	Kw.-hr.	Cost	Month	Kw.-hr.	Cost
January	266	$10.64	August	984	$29.52
February	278	11.12	September	922	27.66
March	294	11.76	October	656	26.04
April	354	14.16	November	490	19.60
May	388	11.64	December	338	13.52
June	514	15.42			
July	616	18.48	Totals	6100	$209.56
Average rate		3.43 cents			

In this connection an interesting rate is offered to butchers by the Public Service Electric Company, which charges them 4 cts. per kw.-hr. for the consumption in each month from October to April inclusive, and 3 cts. per kw.-hr. for the consumption in each of the five remaining months.

The Economy of Storing Artificial Ice in a Large Plant. Mr. R. P. Kehoe has presented some carefully worked-out estimates in Power, June 18, 1912, showing the total investment (estimated) for a 100-ton ice-making plant under the simple can-system and a 60-ton ice-making plant of the same system and a 60-ton ice-making plant under the plate system, the two latter with provision for storing 5000 tons of ice, one refrigerated and the second not refrigerated. The following is a summary of these figures:

100-TON PLANT

Complete mechanical equipment	$54,000.00
Building and foundations	30,000.00
Total investment	$84,000.00

Daily operating expense

16 tons of coal at $3.50	$56.00
One chief engineer	5.00
One night engineer	3.50
Two firemen at $2	4.00
Four tankmen at $2	8.00
Two laborers or storehousemen at $2	4.00
Two oilers at $2	4.00
Ammonia, oil, waste and supplies, etc.	10.00
Office man	4.00
	$98.50

TABLE XLV. YEARLY COSTS OF ICE MAKING

	Investment	Daily operating expense	Total yearly expense	Estimated profit	Percentage of profit to investment
100-ton can ice-making plant	$84,000	$98.50	$30,075	$14,925	17.8
60-ton can ice-making plant and 5000 tons ice storage, refrigerated	75,000	67.00	31,060	13,940	18.6
60-ton plate ice-making plant and 5000 tons ice storage, not refrigerated	100,000	41.50	23,840	18,660	18.66

Month	Approx. average output in tons of 100-ton plant to supply usual demand		With 60-ton plant excess which must be supplied from storage	Proposed time of production for storage purposes	Proposed schedule of 60-ton plant to meet usual demand of 100-ton plant
	Daily	Monthly	Monthly	Monthly	Monthly
January	15	450	....	150	...*
February	10	300	....	1500	1800
March	25	750	....	1500	1800
April	25	750	....	1500	1800
May	50	1500	....	300	1800
June	100	3000	1200	....	1800
July	100	3000	1200	....	1800
August	100	3000	1200	....	1800
September	75	2250	450	....	1800
October	50	1500	....	....	1800
November	25	750	....	....	1800
December	25	750	....	....	...*
Total		18,000	4050	4050	18,000

* Overhauling and repairs.

Depreciation, etc.

5% depreciation on machinery ($54,000)	$2,700.00
2% depreciation on building, etc. ($30,000)	600.00
Repairs, taxes, water and incidentals (5%)	4,200.00
	$7,500.00

Summary

180 days' full operation at $98.50	$17,730.00
Labor for balance of year, leaving out only two laborers = 180 days at $28.50	4,845.00
Depreciation, etc.	7,500.00
	$30,075.00
Income from sale of 18,000 tons of ice at $2.50	45,000.00
Profit ....$45,000 — $30,075 = $14,925 = 17.8%	

60-TON PLANT WITH 5,000 TONS STORAGE, REFRIGERATED

Complete mechanical equipment	$40,000
Building and foundations	35,000
Total investment	$75,000

Daily Operating Expense

(For 60 tons ice production)

10 tons of coal at $3.50	$35.00
One chief engineer	5.00
One night engineer	3.50
Two firemen at $2	4.00
Two tankmen at $2	4.00
Two laborers or storehousemen at $2	4.00
Ammonia, oil, waste and supplies, etc.	7.50
Office man	4.00
	$67.00

Ice Storage

Entire refrigerating work = 40 tons, requiring 3 tons of coal at $3.50	$10.50

Depreciation, etc.

6% depreciation on machinery ($40,000)	$2,400.00
2% depreciation on building, etc. ($35,000)	700.00
Repairs, taxes, water and incidentals (6%)	4,500.00
	$7,600.00

Summary

10 months' full operation, 300 days at $67.00	$20,100.00
Carrying full ice storage for about 6 months, 180 days at $10.50	1,890.00
All labor during two months' shutdown, 60 days at $24.50	1,470.00
Depreciation, etc.	7,600 00
	$31,060.00
Income from sale of 18,000 tons of ice at $2.50	45,000.00
Profit ....$45,000 — $31,060 = $13,940 = 18.6%	

60-TON ICE-MAKING PLANT — PLATE SYSTEM

(Compound condensing steam engine, 5000 tons ice storage)

Complete mechanical equipment	$60,000.00
Building and foundations	40,000.00
	$100,000.00

Daily operating expense
(For 60 tons ice production)

5 tons of coal at \$3.50	\$17.50
One chief engineer	5.00
One night engineer	3.50
Two firemen at \$2	4.00
Two harvesters at \$2	4.00
Ammonia, oil, waste, supplies, etc	7.50
	\$41.50

Depreciation, etc.

6% depreciation on machinery (\$60,000)	\$3,600.00
2% depreciation on building (\$40,000)	800.00
Repairs, taxes, water and incidentals (6%)	6,000.00
	\$10,400.00

Summary

10 months' full operation, 300 days at \$41.50	\$12,450.00
All labor during two months' shutdown, 60 days at \$16.50	990.00
Depreciation	10,400.00
	\$23,840.00
Income from sale of 17,000 tons of ice (assuming loss of 1000 tons through meltage) at \$2.50	42,500.00
Profit	\$42,500 — \$23,840 = \$18,660 = 18.66%

The calculations are based on a wooden structure for storage with the inexpensive insulation and a 50% yearly load-factor, allowing space enough for 5000 tons of ice and room for handling which he estimates is taken care of by a building 200 ft. long, 100 ft. wide and 12.5 ft. high; the total wall, floor and ceiling surfaces aggregating 47,500 sq. ft. He allows a heat leakage of 5 B.t.u. per sq. ft. per degree difference in temperature every 24 hrs. The average temperature difference between the outside and the interior of the storage has been estimated as 50° F. Calculating that each sq. ft. of pipe surface will absorb 50 B.t.u. per degree difference in temperature every 24 hours, and assuming a back pressure of 15 lbs. equivalent to an ammonia temperature of 0° F. equals a temperature difference of about 30° F. The refrigerating work would be $\frac{47,000 \times 5 \times 50}{288,000} = 40$ tons, and the amount of 2 in. piping required for the storage would be 47,500 times 5 times 50 times 1.6 over 30 times 50 equals 12,667 ft. The approximate cost of this piping would be \$5000 erected in place. Mr. Kehoe has figured 6% for depreciation, repairs, etc., in the 60-ton plant and 5% in the 100-ton plant, considering that the smaller plant will have to run 67% more of the time each year.

He considers that he has favored the 60-ton plant as much as possible in his figures. The yearly profit is \$1000 less and the percentage of earnings is very little more.

The original investment of the 60 ton can plant is less than that of the 100 ton can plant, and that of the 60-ton plate plant is ⅓ more than that of the 60 ton can plate. Hence he concludes that in the three propositions, as an investment, there is little to choose,

the whole question depending upon the local facts and figures given in the detailed cost of construction, that must be estimated with great care independently of any particular set of cases.

Cost of Ice Houses. For detail costs of ice houses see Gillette's Handbook of Cost Data.

Cost of Equipment for 10-Ton Refrigerating Plant Using Machines of Different Sizes. (Power, Sept. 19, 1910.)

Capacity of compressor, gas at 0°F	10 tons	15 tons	20 tons
Operating temp., gas at	0°F.	12°F.	0°F.
Brake h.p. with 185 lb. condenser pressure, incl. 25% increase over the compressor h.p.	21.3	32.4	42.5
Brake h.p. gas engine bought	25	35	45
Cost installed, with countershaft and belting, dollars	1100	1500	1850
Cost of horiz. belt-driven ammonia compressor, with high pressure side, erected, dollars	2300	2900	3500
2-in. wrought iron expansion piping required, lineal ft.	2332	7212	4663
Cost of piping, including liquid and suction connections, cts. per ft.	57	54	55
Total cost of piping, dollars	1329	3890	2565
Prime charge of anhydrous ammonia, lb.	750	2000	1400
Cost at 26 cts. per lb.	195	520	364
Total first cost of each plant, dollars	$4924	$8810	$8279

Comparative Data on Three Machines and Cost Figures.

	Summer	Autumn	Winter	Spring	Total for year
Tons refrigeration required per season	905.45	656.11	241.15	453.18	2,255.89
10 ton machine:					
Hours running daily	45	17.3	6.36	11.95	......
Hours running per season	2,184	1,574	579	1,088	5,425
Per cent. of possible running time, 364 days x 24 equals 8,736 hours	....	....	....	....	62.1
Brake h.p. hours, 5425 x 21.3 equals	....	....	....	....	115,553
Water, M. gal. (same for all machines)	....	....	....	....	3,255
Tons refrigeration required per season	905.45	656.11	241.15	453.18	2,255.89
15 ton machine:					
Hours running, daily	12.4	9	3.3	6.2	......
Hours running per season	1,128	819	300	564	2,811
Per cent. of possible running time	....	....	....	....	32.2
Brake h.p. hrs.	....	....	....	....	91,076
20 ton machine:					
Hours running, daily	12	8.65	3.18	5.98	......
Hours running per season	1,092	787	290	544	2,713
Per cent. of possible running time	....	....	....	....	31
Brake h.p. hrs.	....	....	....	....	115,301

Costs per Year.

Size of machine used	10 tons	15 tons	20 tons
Gas bill	$2,888.83	$2,276.90	$2,882.53
Lubricating oil	69.33	54.65	69.18

Water bill	$162.75	$162.75	$162.75
Ammonia loss, 10, 6 and 7%, respectively	19.50	31.20	25.48
Wages	1,627.50	843.30	813.60
Total net operating expenses	$4,767.91	$3,368.80	$3,953.54
Fixed charges	738.60	1,321.50	1,241.85
Total yearly cost	$5,506.51	$4,690.30	$5,195.39
Total net operating expenses per ton refrigeration	2.12	1.50	1.75
Total yearly cost per ton refrigeration	2.44	2.08	2.30
Total yearly cost per cu. ft. storage space *	9.18c	7.82c	8.66c
Total yearly cost saved over 10 ton machine	......	816.21	311.12
Years required to recover excess first cost over 10 ton machine	......	4.76	10.8

* These costs are about one-third of the rental charged per cu. ft. per yr.

Power Consumption for One Year in Electrically Operated 100 Ton Ice Plant. (Journal Western Society of Engineers, September, 1911.)

1910	Tons of ice Per month	Tons of ice Average daily	Max. h.p. required	Total h.p.-hrs.	Max. h.p. per ton	H.p. hrs. per ton
Jan.	1768	57.0	123	87,070	2.16	49.24
Feb.	1549	55.3	137	79,450	2.48	51.29
March	1903	61.4	221	93.760	3.60	49.27
April	2732	91.1	232	164,558	2.55	60.23
May	2651	85.5	257	165,488	3.01	62.42
June	3024	100.8	300	188,666	2.98	62.39
July	3442	111.0	314	219,265	2.83	63.70
Aug.	3503	113.0	300	208.123	2.65	59.40
Sept.	3514	117.1	291	209,027	2.49	59.48
Oct.	3379	109.0	283	185,177	2.60	54.80
Nov.	982	32.7	137	88,070	4.19	89.68
Dec.	1853	59.8	129	93,914	2.16	50.68
Total	30300			1,772,568		58.50

Coal at $2.50 per ton, consumption was 85.47 lbs. per ton ice for evaporation and distillation.

Cost electric power	23.36 cts.
Cost fuel	10.68 cts.
Cost engine and boiler labor	15.51 cts.
Cost tank and ice labor	12.55 cts.
Total	62.10 cts.

NON-DISTILLED WATER. PLATE SYSTEM

1910	Tons of ice Per month	Tons of ice Average daily	Max. h.p. required	Total h.p.-hrs.	Max. h.p. per ton	H.p. hrs. per ton
Jan.	0	0	0	10,314	0	0
Feb.	1420	50.7	145	98,214	2.86	69.2
March	1400	45.2	153	105,845	3.38	75.6
April	1168	38.9	139	78,933	3.58	67.6
May	1786	57.6	138	101,798	2.40	57.0
June	1037	34.6	278	120,720	8.00	116.4

1910	Tons of ice Per month	Tons of ice Average daily	Max. h.p. required	Total h.p.-hrs.	Max. h.p. per ton	H.p. hrs. per ton
July	2294	74.0	280	201,791	3.78	88.0
Aug.	1800	58.1	290	209,200	4.98	116.2
Sept.	2244	74.8	283	198,157	3.78	88.3
Oct.	1115	36.0	149	117,363	4.13	105.3
Nov.	1019	34.0	141	98.320	4.14	96.5
Dec.	1356	43.7	139	104,398	3.19	77.0
Total	16639			1,145,053		86.8

Total cost electric power per ton ice 35.56 cts.
Total cost of labor per ton ice...36.00 cts.

71.56 cts. including Ltg. and Aux.

Electric power rate $36.00 h.p. year when month demand was 100 h.p.
Electric power rate $32.50 h.p. year when month demand was 200 h.p.
Electric power rate $30.00 h.p. year when month demand was 300 h.p.
At similar steam plant cost per ton ice was 58.06 cts.; power was a by-product.

Data from Several Small Ice-Making Plants. (From data in Isolated Plant and Electrical World in 1913.)

A 4-Ton Plant in Combination with an Electric Light Plant, in a Texas town of 1200 population, manufactured 700 tons of ice for the local population per year while the ice equipment represents an investment of about $5,000. There is also a small vault about 6 ton capacity for storage. The monthly operating expenses for

Fuel	$300.00
Labor (including office help)	100.00
Supplies and miscellaneous	25.00
Delivery	30.00

Nothing seems to be allowed for depreciation and repairs in this statement. The total plant cost to produce one ton of ice on the station platform is estimated at $3.50 and the product is sold wholesale for $8.00 per ton. The local domestic price for delivered ice being $.50 per 100 lbs. The annual gross income from the ice business was $5400.00, annual expenses, including depreciation, interest, etc., $2520.00, leaving net income on the investment of $5,000.00, $2,880.00.

A 6-Ton By-Product Ice Plant in Combination with a Small Electric Central Station in Georgia Marketing 1500 *Tons of Ice per Year in a Town of* 1000 *Inhabitants.* Steam compression apparatus was used for handling the ammonia. The total investment, including the buildings and refrigeration plant, was about $10,000.00. The year's operating expense being as follows: —

Fuel	$750.00
Labor, including office	400.00
Miscellaneous	50.00
Delivery	280.00

Total $1,480.00, not including interest, depreciation and repairs. The estimated cost of producing 1 ton of ice at the platform was $3.60, and the receipts wholesale on the platform were $4.30 per ton. Deliveries at retail were made to small customers at $8.00 per ton, one wagon being found adequate to supply the retail trade. The annual receipts and disbursements from the ice business were as follows: —

The annual gross income from ice business	$2250.00
Annual expenses (including depreciation, int., etc.)	1730.00
Balance	$ 520.00

A 10-*Ton Plant Operated in Conjunction with the Electrical Equipment of an Electric Company in Omaha* with a population of 3500 representing an investment of about $10,000.00 and producing 1200 tons annually at a net cost of $1.28 per ton under full-load operating conditions, where the ice-making season lasted four months. The plant account was as follows: —

Compressor plant, freezing tank, etc.	$9,000.00
Teams and wagons	500.00
Miscellaneous equipment	500.00

The domestic price for ice delivered was $.45 per 100 lbs., while, at wholesale, on the platform, the price was $4.00 per ton. The plant includes a cold storage room for holding 75 tons of ice under artificial refrigeration. The plant expenses chargeable to ice making in 1912 were $1550.00, including depreciation, interest, etc., and the gross income from the ice business was $7500.00.

A 10-*Ton Ice Plant Operated by an Electric-light Company* in a town in Northern Texas with 2000 population manufactured 2000 tons of ice per season and the plant costs as a going concern $16,000.00 including a well furnishing cooling water. Distilled water was used for making the ice, and the daily operating costs amounted to $30.42, including $12.50 for fuel, $13.42 for labor, including office help; $3.50 for delivery and $1.00 for miscellaneous expenses. The cost per ton of ice to the company was figured at $2.74 on the station platform. The wholesale receipts were $4.00 per ton and on a retail basis, delivered, the price was $9.50 per ton. The total gross revenue was $12,000.00 per year, the total operating expenses were $9800, leaving a balance of $2200.00 or 13.75 per cent. on the investment. It does not appear whether or not the depreciation and repairs were included in the above statement, but even if they were not, the figures indicated the cost of the business when the ice plant is used in connection with an electric light business.

A 10-*Ton Combination Ice Electric Plant in Florida* sells 1700 tons of ice per year in the community of 1700 population. This station utilizes the exhaust-steam from its electric-plant engines to operate a 10 ton absorption-type "generator," and the distilled water from the steam engine is reclaimed for freezing into ice. The ice plant, including building, equipment, can tank, two de-

livery wagons, etc., represents an investment of $12,000. The wholesale price of ice is from $5.00 to $7.00 per ton and the retail domestic price is $.50 per 100 lbs. delivered. The 1912 gross business was $12,000, and the expenses including depreciation, interest and all other charges were $7000.00, leaving net profits of $5000.00 or 42% on the original investment, which is suspiciously high.

A 15-Ton Ice Plant Operated by an Electric Company in Kentucky, serving a population of 3000, representing an investment of $9500.00 for the local ice business, the equipment comprising steam-driven ammonia-compression apparatus, with 36 tons' storage capacity. The actual plant cost of freezing a ton of ice including fuel, labor, etc., averages about $2.00 and the product is sold at wholesale on the platform for $5.00 per ton. The retail rate was $8.00 per ton delivered. The gross income from the ice business during 1912 was $6100.00. The expenses including fuel, labor, depreciation, etc., amounted to $2500.00, leaving $3600.00 net or about 40% on the ice plant investment.

A 12.5-Ton Ice Plant in Combination With an Electric Plant in Central Nebraska involved an investment of about $13,200.00 and produced for a local population of 3200, 1250 tons of ice in 1911 and 775 tons in 1912. The ammonia compressor is motor-driven, and distilled water is obtained from the electric generating department by condensation. To freeze 1 ton of ice at this plant 58.5 kw.-hr. of energy is required, the ice department being charged for this at the rate of 3.5 cts. per kw.-hr., this making the actual cost of producing a ton of ice at the station platform about $2.50. The cost to deliver locally to retail customers was about $1.20 per ton in addition. The retail rate for ice was from $.25 to $.50 per 100 lbs. and the wholesale price for ice sold locally was $3.00 to $4.00 per ton. The company's statement of its earnings was for annual income from the ice business $7825.00 and the expenses, depreciation, interest, etc., $6262.00, net returns $1563.00. The plant here included a 30-ton cold-storage house, which, according to the statement of company was not sufficient for the best results.

A 15-Ton Steam-Driven Ice Plant. In a Kansas town of 2300 inhabitants manufactured 2800 tons of ice per year from distilled water obtained by the condensation of the various plant engines, including the ammonia compressor. The investment in the ice business is represented by the following figures:

Ice-plant addition to building	$ 2,000.00
15-ton steam-driven compressor	13,000.00
Freezing-tank equipment	1,200.00
Wagons	500.00
Total ice-making investment	$16,700.00

In addition to the refrigerating equipment proper, cold-storage capacity for 1000 tons of ice was installed, an additional amount of $6000.00 making the total outlay for the ice department $22,-700.00. The factory cost of making a ton of ice at the station platform was $1.35 estimated as follows: —

Fuel	$0.75
Labor, including office salaries	0.30
Water	0.10
Supplies and miscellaneous	0.15
Total	$1.35

The wholesale price was $2.75 per ton. The local retail price delivered is $.35 per 100 lbs. The cost of delivery averages about $1.30 per ton.

Yearly gross income from ice business	$12,000.00
Expenses for year, including depreciation, etc.	9,420.00
Net earnings from ice business	$ 2,580.00

An 18-*Ton Ice Plant in Iowa* in a town of 4500 inhabitants manufactured 3500 tons of ice during seven months of 1912 with the following operating expenses:

Fuel	$1,690.77
Labor and office help	2,000.00
Water	200.00
Supplies, miscellaneous	150.00
Cost of delivery	1,803.87
Total (not including depreciation, int., etc.)	$5,844.64

The actual plant cost of producing a ton of ice at the platform was estimated at $1.32 and the retail rates are on a sliding scale. Deliveries are made to groceries, hotels, restaurants and similar customers who use from 1 to 5 tons of ice during the season at the rate of $8.00 per ton; between 5 and 20 tons, the rate is $5.00 per ton and between 20 and 50 tons, the rate is $4.00 per ton, all delivered. Larger customers and those using 50 tons per year have special contracts. There is a flat rate of $8.00 per ton for ice delivered to all residences. The annual receipts were $13,039.74 and the annual expense, including interest, depreciation, etc., was $6,826.68, leaving net income from ice business of $6,213.06, which on a total plant investment, inclusive of delivery wagons and storage facilities is $12,200.00, just over 50%.

A 20-*Ton By-Product Ice Plant in Kansas*. Cost as follows for the ice department:

Plant addition to building	$10,000.00
Steam compressor outfit, tank, etc.	17,000.00
Wagons and teams	2,000.00
Total investment	$29,000.00

Operating expenses were as follows, omitting interest, taxes, depreciation, etc.:

Fuel	$2,500.00
Labor, including office help	1,200.00
Water	300.00
Supplies	500.00
Delivery	1,300.00
Total	$5,800.00

The cost of manufacture was figured at $1.50 per ton and the average wholesale price was $3.65 per ton, the retail price being $.35 per 100 lbs. The yearly income from the ice department was $12,860.00, and expenses, including interest and depreciation, were $9,400.00, leaving net return of $3460.00, 12% on the investment.

A 20-Ton By-Product Ice Plant in Tennessee with 5000 population made 3000 tons of ice in 1912. The investment being as follows for the ice plant:

Ice machine; freezing tank, etc.	$15,000.00
Addition to building	3,000.00
Delivery wagons	2,000.00
200-ton ice storage room	1,000.00
Total	$21,000.00

1912 was a poor year for the ice business from that location owing to a cool summer, but the annual gross income from ice making was $15,000.00 and the annual expense, including interest, depreciation, etc., $13,000.00, giving net returns of $2000.00, or nearly 10% on the investment.

A 21-Ton By-Product Ice Plant near Omaha produces 2700 tons of ice per year for a community of 8000. The profitable part of the business was seven months in the year, but it is operated for the remaining five months for the convenience of some of the customers. The total ice-plant investment was about $25,000.00 and the gross income in 1912 from the ice business was $8200.00, and the expenses, including interest, etc., were $5200.00, leaving net return of $3000.00 or about 12% on the investment. The average cost of producing a ton of ice was $2.00 and the wholesale rate to a local dealer was $3.00 per ton. The local dealer retailed and delivered it at $.40 per 100 lbs.

A 10-Ton By-Product Plant in a Small Western Town with Less Than 3000 *Inhabitants* had an ice-making investment of $11,000.00 and earned $1,238.00 net, or a little over 11% in 1912. The following tables give the percentage of sales for the different classes of customers in quantity of ice and the percentage of gross income obtained from these customers:

Class of customer	% of total deliveries	% of gross income
Railroad company	62	36
Wagon and ice book sales	28	48
Butcher shops	5	7
Lobby sales	3	6
Out-of-town customers	2	3
Total	100	100

The total output for a season of eight and a half months was 1967 tons of ice sold in wholesale lots at a figure of between $3.00 and $4.00 per ton, the retailed price being from $8.00 to $10.00 a ton delivered. The cost of producing and delivering one ton of ice was as follows:—

Fuel	$1.270
Labor, including clerical work	0.860
Water	0.080
Oil	0.050
Ammonia	0.060
Light	0.150
Supplies	0.190
Insurance on plant	0.025
Interest on investment	0.320
Depreciation	0.400
Delivery	0.525
Total	$3.930

A 30-Ton Plant in Missouri Connected with an Electric Lighting Plant. In a commmunity of 5000 manufactured 8000 tons of ice per year costing about $1.15 per ton for manufacturing about the same amount for delivery.

A 100-Ton Ice-Making Plant, described by Mr. C. E. Rose in Electrical World, was operated by the Arkansas Cold Storage Company at Little Rock. It produced a refrigeration for a cold-storage warehouse of 100,000 cu. ft. capacity, a street pipe-line of 42,000 cu. ft. capacity and two freezing tanks, an output of 40 tons of raw-water ice per day each. The refrigerating machinery included two vertical duplex Frick gas pumps rated at 50 tons per day each when running at 77 r.p.m. with standard refrigerator and condenser pressures. In addition to this, 100 h.p. was installed in various motor units of from 2 to 25 h.p., used to drive the circulating-water, brine pumps, air compressors, agitators, etc. For the year ended October 1, 1912, there were the following operating figures:

Tons of refrigeration manufactured	13,123
Kilowatt-hours produced	497,608
Kilowatt-hours per ton of refrigeration	37.9
Fuel oil for power, per ton of refrigeration	$0.124
Wages for power per ton of refrigeration	0.170
Lubricating oil and waste per ton of refrigeration	0.074
Water per ton of refrigeration	0.030
Electricity purchased per ton of refrigeration	0.012
Maintenance of oil engines per ton of refrigeration	0.013
Maintenance of refrigeration plant per ton of refrigeration	0.008
Maintenance of electric equipment per ton of refrigeration	0.013
Maintenance of auxiliary equipment (pumps, air compressors, etc.) per ton of refrigeration	0.007
Total engine-room expense per ton of refrigeration	$0.451

The above figures were obtained by the use of oil engine drives implying two 120 h.p. vertical, three-cylinder Diesel oil engines.

The following year, ending Oct. 1, 1913, electric current was purchased from an electric light company on the basis of the regular primary rate of $1.00 per kw. maximum demand plus an energy charge of 1 cent net per kw.-hr. for the electricity consumed by the motors, with the understanding that the refrigerating plant would not run during the electric light company's peakload period. The conditions of the following costs were obtained:—

Tons of refrigeration manufactured	19,899
Kilowatt hours	750,401
Kilowatt-hours per ton of refrigeration	38

Wages for power per ton of refrigeration	$0.106
Lubricating oil and waste per ton of refrigeration	0.030
Electricity purchased per ton of refrigeration	0.235
Water per ton of refrigeration	0.005
Maintenance of electric plant per ton of refrigeration	0.010
Maintenance of refrigerating plant per ton of refrigeration	0.035
Maintenance of auxiliary equipment per ton of refrigeration	0.024
Total engine-room expense per ton of refrigeration	$0.445

On this second year of operation on account of the larger amount of ice sold the total costs were figured at $.96 per ton, whereas for the previous year with oil-engine drive, the costs were figured at $1.22 per ton of refrigeration. The increase in refrigeration capacity was obtained by speeding up the ice machines from 77 r.p.m. to 116 r.p.m. The indicator cards showing that while at the high speed the area of the card was slightly reduced, the reduction was trivial in comparison with the larger increase in the volumetric displacement of the machine per unit of time; the net gain in refrigerating capacity being 24 tons per day, rating the plant at 148 tons instead of 100 tons as was the case with the oil-engine equipment.

Cost of Refrigeration for a Skating and Curling Rink. There were two public ice surfaces, one of 22,000 sq. ft. for skating, and the other of 5700 sq. ft. for curling. The rink floors being covered with 1.25 in. iron pipe laid 4.75 ins. apart, center to center, and embedded in gravel to the tops of the pipes, connected to headers running along each side of the rink. These pipes are divided into sections of eight each for easy connection and repairs. They include 55,860 linear ft. of pipe in the larger rink and 13,707 ft. in the curling rink. The ice surface is built up by spraying the pipes with water, the ice being kept at a thickness of from 1.5 in. to 2 ins. above the pipe. The refrigerating plant, of the compression type, consists of one 400 h.p. boiler with feed pump and auxiliaries, two 16 in. by 30 in. by 24 in. single-acting York compressors driven by Corliss cross-compound steam engines, an ammonia condenser, a brine cooler, pumps and tanks. The feed water passes through an exhaust-steam heater of 500 h.p. capacity. The compressor engines operate at 125 lbs. boiler pressure, exhausting into a 22 in. vacuum. The ammonia condenser consists of eighteen coils of 1.25 in. and 2 in. pipe, twelve pipes high and 19 ft. long, and is supplied from the city mains in conjunction with the water from the surface wells on the premises. This water after leaving the condenser passes through the steam condenser and thence to the sewer, as no cooling tower is provided. The brine cooler is equipped with ten coils of 2 in. and 3 in. pipe 18 ft. long and fourteen pipes high, arranged in two banks, the brine being stored in a 24 ft. by 10 ft. by 8 ft. tank. It is forced through the cooler and floor piping by two Gould triplex double-acting 8.5 in. by 10 in. pumps driven through gearing from a line shaft run by an 8 in.

by 10 in. horizontal engine. The brine for the curling rink is supplied by a duplex double-acting pump having a capacity of 150 gal. per min. The steam for heating the building is taken from the boiler through a reducing valve, the indirect system being used, in which air is drawn in over steam coils by a fan run by a 15 h.p. motor. A similar motor and fan are used to exhaust the vitiated air from the building. The brine in this plant is composed of a solution of calcium chloride and water, having a specific gravity of 1.185. It passes through the floor piping of the rink at a temperature of about 14 deg. F., returning to the tank at about 16 deg. F., after which it is forced by the pumps into the cooler.

The cost per day of operating the plant by steam power was as follows: Electricity for light and ventilation service, $11.55; water, $23.85; coal, $24.54; oil and waste, $.15; attendance, $16.00; insurance, $.75; depreciation, $9.05; taxes, $2.47; interest, $6.03; total $94.39. The lighting service required 135 kw.-hr. per day with 27.3 kw.-hr. motors driving fans, the cost of electricity for lighting and ventilation averaging 6.8 cents per kw.-hr. The coal consumption was 12,270 lbs. of coal per day, costing $4.00 per ton. The water consumption was 18,377 cu. ft. per day, 608 cu. ft. per hour being used for condensing purposes and wasted into the sewer. The investment cost of the plant was $55,000.00, the load-factor on a twenty-four hour run being 50%, the average peak for one hour being 110.8 kw. maximum. Considerable savings could be made by converting this plant to electric.

Electrical Refrigeration at 11.7 Cents a Day. (Electrical World, May 8, 1915.) In the month of July last year R. W. Brown conducted tests on an electrical refrigerator to obtain authoritative data on the average daily energy consumption of the device. The refrigerator used for the tests was of the type made by the Mechanical Refrigerator Company of Chicago. It was 16 ins. by 36 ins. by 50 ins. inside. During the tests the automatic thermostat was disconnected and the control was effected by hand so that accurate observations of time and temperatures could be made. The temperature of the kitchen in which the machine was operating was read five times a day, and the coil temperature was read each time the room temperature was taken and again each time the motor was started or stopped. The temperature maintained throughout the test in the warmest part of the refrigerator ranged between 40 deg. and 45 deg. F., and in the compartment containing the cooling coils the temperature was considerably lower. One day during the test ice for table use was made in the refrigerator.

At a 10 cent rate for electrical energy, such as is in force at Spring Valley, its average daily cost amounted to 11.7 cents. The data observed by Mr. Brown are given in Table XLVI.

Comparative Installation and Operating Costs of a Combined Ice-Manufacturing and Cold-Storage Plant. (R. H. Tait and L. C. Nordmeyer in Power, Oct. 28, 1913.)

The basis of this comparison is a plant having a capacity of 60 tons of ice per day of 24 hrs., and a cold-storage capacity of 100,000 cu. ft. The cost of building and machinery equipment is

TABLE XLVI. OPERATING DATA ON A MOTOR DRIVEN REFRIGERATOR

Average temperature of room	83 deg.
Average temperature of coils	92 deg.
Average pressure in lbs. per sq. in.	57 deg.
Average time of operation daily	5 hrs., 16 min.
Average daily consumption, kw.-hrs.	1.17

figured three ways: First, with a simple steam plant; second, with a compound condensing plant; and, third, with the Diesel engine. The cold-storage space will require a refrigerating capacity of 20 tons, which is equivalent to 12 tons of ice-making capacity. The refrigerating machines and equipment must, therefore, be capable of developing the equivalent of 72 tons of ice-making capacity for 24 hrs. daily.

In the latitude of St. Louis it has been found that if the output of the month of July is figured at full capacity, then the output in July is approximately 15 per cent. of the annual output. In the case under consideration, the yearly work is, therefore, equivalent to

$$\frac{72 \times 31 \times 100}{15} = 14{,}880 \textit{ tons of ice}$$

It is assumed that the plant would be erected in the Southwest, and fuel oil is figured at 95 cts. per bbl. of 42 gals. Artesian water is available at 87 deg. F. and city water at 90 deg. F.

Buildings. The cost of the buildings, including boiler and engine room, freezing-tank room, cold-storage house and all insulation will be approximately $60,000. The necessary building space will be practically the same for all three types of plant. The fixed charges against the building are for interest, 6 per cent.; insurance and taxes, 1.5 per cent.; depreciation, 5 per cent., making a total of 12.5 per cent. of $60,000, or $7500 per year. Inasmuch as 14,880 tons of ice represent the year's work, the building charge will be 50.4 cts. per ton of ice.

Simple Steam Plant. In this plant it is contemplated to use air lifts to pump the water from the artesian wells to furnish the necessary water for the plant in connection with a water-cooling tower. The mechanical equipment will include water-tube boilers, boiler-feed pumps, feed-water heater, smoke-stack, two 60-ton refrigerating capacity machines, ammonia-compression system, distilling system, freezing system, steam and exhaust connections, air lifts and air compressor, circulating-water pumps, cooling tower, piping for cold-storage rooms, brine pumps, brine cooler, all steam, brine and ammonia pipe covering, 60-kw. generator and engine, ammonia, calcium and foundations for machinery. It is estimated that the complete equipment, delivered and erected, including engineers' fees, will be $65,000. The total cost of the plant, including building and machinery, will, therefore, be $125,000. The auxiliary pumps about the plant will consist of duplicate units, one steam-driven and one electrically driven.

It is estimated that there will be burnt 3.08 bbls. of oil per hour

under the boilers when operating at full capacity. With oil costing 95 cts. per bbl. and the capacity being 72 tons ice making, the fuel cost per ton of ice will be

$$\frac{3.08 \times 95 \times 24}{72} = 97.6 \text{ cts.}$$

The operating cost is estimated as follows:

Two firemen at $720 per year	$1440
Two engineers at $1230 per year	2460
Two oilers at $720 per year	1440
One handy man	900
Oil waste, etc.	300
Total	$6540
$\frac{\$6540}{14{,}880}$ =	$0.439 per ton of ice
Ice handling	0.14 per ton of ice
Total operating expenses	$0.579 per ton of ice

Fixed charges on the mechanical equipment are for interest on machinery investment, 6 per cent.; insurance and taxes, 1.5 per cent.; depreciation and obsolescence, 5 per cent., making a total of 12.5 per cent. on $65.000 or $8125. Fixed charges per ton of ice are then $8125 ÷ 14,880 = $0.546. The total cost per ton of ice is given in the following:

Fixed charges	$0.546
Fuel	0.976
Operating expenses	0.579
Total	$2.101
Fixed charges on building	0.504
Total cost	$2.605

Attention is called to the fact that the total cost of ice, as given above and in the later deductions, is higher than the actual cost of ice at the platform, owing to the fact that the fixed charges on the machinery and building include the fixed charges on the brine cooler, brine pumps, cold-storage house piping, cold-storage house building and insulation which should be properly charged against the cold-storage house only. As these are the same in each case considered, the costs given in each case will not affect the comparison. As the ammonia cost will depend on the care given the plant, and should be the same for each, it has not been used in the estimated cost per ton in making the comparison.

Compound Condensing Steam Plant. In this plant the water will be pumped from the artesian wells in the same manner as in the simple steam plant. The engines on both of the refrigerating machines and on the generator will be compound condensing. The boilers will be equipped with economizers, so that the best efficiency may be obtained in the complete plant. The complete cost of the mechanical equipment including engineers' commission, is estimated at $76,400.

When operating under full load there will be consumed 2.38 bbls. of oil per hour, making the fuel cost $2.26 per hour, or $0.753 per ton of ice. The operating expenses for labor, oil, waste, etc., will be $0.579 per ton of ice, the same as for the simple steam plant. The fixed charges against the investment will be 0.125 × $76,400 = $9550 = $0.642 per ton of ice. The total cost per ton of ice is, therefore, given in the following:

Fixed charges	$0.642
Fuel	0.753
Operating cost	0.579
Total without building charge	$1.974
Building charge	0.504
Total cost	$2.478

The complete cost of plant is as follows:

Cost of machinery	$76,400
Cost of building	60,000
Total cost	$136,400

Diesel Engine Plant. In this plant city water will be used for the making of raw-water ice and for the cooling-tower make-up. All auxiliaries around the plant will be driven by electric current. Power will consist of two 225-b.h.p. Diesel engines, to each of which will be belted one 60-ton refrigerating capacity machine and one 40-kw. generator. The complete mechanical equipment will consist of two 225-h.p. Diesel engines, two 40-kw. belted generators, switchboard, two 60-ton refrigerating capacity belt-driven refrigerating machines, compression system, raw-water ice-freezing system, cooling tower, two centrifugal water-circulating pumps, cold-storage piping, two triplex brine pumps, brine cooler, brine and ammonia pipe covering, ammonia, calcium chloride, two oil tanks, foundations for refrigerating machines, Diesel engines, etc. It is estimated the complete equipment will cost $83,923, including engineer's commission.

The fixed charges against the mechanical equipment will be as follows:

Interest on investment	6 per cent.	
Insurance and taxes	1½ per cent.	
	7½ per cent. of $83,923 =	$6294
Depreciation and obsolescence on oil engines	10 per cent. of $34,440 =	$3444
Depreciation and obsolescence on remainder of machinery	5 per cent. of $49,483 =	$2474
Total		$12,212

The fixed charges per ton of ice equal $12,212 ÷ 14,880 = $0.821.

When operating at full capacity the power required by the refrigerating machine is estimated to be 282 b.h.p. at the Diesel engine and for the electric units 97 b.h.p., making a total of 379 b.h.p. at the engine. Assuming an oil consumption of 8 gal. per

100 b.h.p.-hr. there would be consumed 30 gals. of oil per hour, making the fuel cost $16.30 per day, or 22.6 cts. per ton ice-making capacity. The operating expenses will be as follows:

Two engineers at $1230 per year	$2460
Two oilers at $720 per year	1440
One handy man	900
Oil, waste, etc.	800
Total	$5600
$\frac{\$5600}{14,880} =$	$0.376 per ton ice
Ice handling	0.14 per ton ice
Total operating cost	$0.516 per ton ice

City water must be supplied for making 60 tons of ice and for supplying the losses of the cooling tower. For this purpose there will be used 263,500 cu. ft. of water per month.

70,000 cu. ft. of water costs	$64.15
193,500 cu. ft. of water at 7c. per 100	135.45
Total water cost per month	$199.60
Water costs per ton of ice	$0.09

From the above the total cost per ton of ice is as follows:

Fixed charges	$0.821
Fuel	0.226
Operating expense	0.516
Water	0.090
Total without building charge	$1.653
Building charge	0.504
Total cost per ton of ice	$2.157

The total cost of the plant will be as follows:

Cost of machinery	$83,923
Cost of buildings	60,000
Total cost	$143,923

Résumé. The comparative cost of installation and operation of the three types of plant is given in the accompanying table.

From the table the following comparisons can be deduced:

Simple vs. Compound Steam Plant: The compound condensing steam plant costs $11,400 more than the simple steam plant, but a saving of 12.7 cts. per ton of ice is accomplished, which for 14,880 tons of ice-making capacity per year amounts to $1889.76 per year. On this basis the compound condensing steam plant will pay for the difference in cost between it and the simple plant in approximately six years.

Simple Steam Plant vs. Diesel Engine Plant: The Diesel engine plant will cost $18,923 more than the simple steam plant, but a saving is accomplished of 44.8 cts. per ton of ice, or $6666.24 per year. On this basis the Diesel engine plant will pay for the difference in cost between it and the simple steam plant in less than three years.

COMPARATIVE INSTALLATION AND OPERATING COSTS

	Simple steam plant	Compound condensing steam plant	Diesel engine plant
Cost building	$60,000	$60,000	$60,000
Cost machinery	65,000	76,400	83,923
Total cost	$125,000	$136,400	$143,923
Cost water per ton ice	......	......	$0.09
Cost fuel per ton ice	$0.976	$0.753	0.226
Fixed charges machinery	0.546	0.642	0.821
Operating cost	0.579	0.579	0.516
Cost per ton ice without building charge	$2.101	$1.974	$1.653
Building charge per ton ice	$0.504	$0.504	$0.504

Compound Condensing Plant vs. Diesel Plant: The Diesel engine plant costs $7523 more than the compound condensing steam plant, but a saving of 32.1 cts. per ton of ice is accomplished, which amounts to $4776.50 per year. From this the Diesel engine plant will pay for the difference in cost between it and the compound condensing steam plant in less than two years' time.

From the comparison given above, it seems apparent that the oil-engine plant would be an exceedingly good investment. This should especially be apparent on account of the manner in which the deductions were made. The steam-driven plants were given the benefit of the best efficiency that could be obtained; namely, a boiler efficiency in the case of the simple plant of 65 per cent.; and in the case of the compound condensing steam plant, with the use of an economizer, of 71.5 per cent.

The steam consumption of the simple engine of the refrigerating machine was assumed to be 27 lbs. per i.h.p.-hr., while that of the electrical generators was assumed to be 30 lbs. of steam per i.h.p.-hr.

In the case of the compound condensing steam plant, a steam consumption of 18 lbs. per i.h.p.-hr. was assumed for the steam engines of the refrigerating machine, and 20 lbs. per i.h.p.-hr. for the generator engines, including steam for vacuum pumps and other auxiliaries.

In the oil-engine plant, the engines were credited with a low efficiency of 8 gals. per 100 b.h.p.-hr., while it has been found that the fuel consumption of engines installed in the Southwest by the Busch-Sulzer Bros.-Diesel Engine Co. was approximately 6.5 gals. per 100 b.h.p.-hr. under normal working conditions. In addition to this, the oil-engine plant is charged with water brought from the city, as against artesian-well water used in the steam plant.

A further advantage is given the steam installations by charging them with a depreciation and obsolescence of only 5 per cent. as against 10 per cent. charged to the Diesel oil-engine installation.

The present prices of fuel oil will somewhat change the figures, as shown, but cannot help but prove the oil engine a good investment.

CHAPTER XX

ELECTRIC RAILWAYS

Electric railway construction has much in common with steam railway construction. The detail cost of steam railroads, including grading, ballast, bridges, etc., is very fully covered in the Gillette's Handbook of Cost Data; hence, in order to avoid repetition, this chapter on electric railway costs is confined to such data as are not given in the book just named.

The engineer who is going very deeply into the subject of electric railway costs, both of construction and operation, will find a mass of valuable data in the reports and files of state railway and public service commissions. A study of such data discloses the somewhat astonishing fact that few interurban electric lines yield even a 6 per cent. return on their cost. If an adequate depreciation annuity were provided, it is probable that not one electric interurban in ten would yield more than 5 per cent. on the actual cost of the physical plant. Perhaps this note of warning is not so greatly needed to-day as it was needed 10 or 15 years ago; but underestimates of first cost, as well as operating expenses and depreciation, are still so common that it seems advisable to caution engineers in the employ of promoters of electric traction lines.

Appraisal of the Spokane and Inland Empire Electric Railroad. The following is condensed from an article by H. L. Gray, Engineering and Contracting, Dec. 27, 1911. The appraisal was made in connection with a rate case. The railway is interstate, but as the mileage in the State of Idaho is comparatively small, it was decided to establish a precedent and appraise the property lying in Idaho, as well as that within the State of Washington, and to show a separate estimate for each state.

Mileage.— This system has a total main track mileage of 234.86 miles, of which 204.52 miles are within the State of Washington, while 30.25 miles are within the state of Idaho. The trackage within the State of Washington includes 47.34 miles of street railway in the City of Spokane. In addition to the above mileage, there is a total of 44.83 miles of other tracks, of which 34.25 miles are in the State of Washington and 10.58 miles within the State of Idaho, making a total track mileage of 279.60.

Construction Features.— The only particularly noteworthy features of construction found on this system exist on the Inland Division. The location of that portion of the line presented unusual

difficulties, owing to the fact that it runs squarely across the drainage systems of the country, necessitating very expensive grading, excessive curvature and heavy grades. The maximum curvature is 12 degs., the average amount of curvature per mile being 105 degs., or almost four times that usually encountered on steam roads. The maximum grade of 2% is frequently encountered.

The single phase, alternating current system of distribution is used on this division, which, although much more expensive as regards first cost, was adopted with the idea that the economy of operation would offset the increased cost of construction. At the time this line was built the single phase system of distribution was largely an experiment, only a few such systems existing in the world. Even after the line was constructed, continual experimenting was necessary in order to perfect the operation. The train records of the company would indicate that so far as concerns the efficiency of operation, this system has been a decided success. On account of the high voltage of the power used, the ordinary motor cars will force their way through the heavy snows of the Palouse country without the aid of a snow plow. The winter of 1910 was undoubtedly one of the most severe ever experienced in this locality, and the first train running over the line in the morning would frequently encounter at least twelve inches of snow on the level, and sometimes as much as seven feet of snow in the cuts. No provision was made to protect the cars, with the exception of an iron sheathing over the pilot, and in spite of such adverse conditions, the longest delay due to snow during the entire winter was twenty minutes.

The trolley construction on this division is of the catenary type, the messenger wire and trolley being supported by mast arms, the messenger wire acting as a conductor. A large portion of the power used is supplied by what is known as the Nine Mile Power Plant, built at a cost of one and one-quarter millions of dollars, being strictly modern and up-to-date in every way. The plant is capable of generating 12,000 k.v.a. working under a 58-ft. head. Power is generated by four 3,000 k.v.a. Westinghouse alternating current generators coupled to four 5,500 hp. Holyoke turbines, under control of Lombard governors, with the additional protection of emergency controllers. In addition to the power generated by this plant, a large amount of power is purchased from the Washington Water Power Company.

Actual Cost.— An investigation of the records showed the present company to be an amalgamation of a number of companies built during previous years, namely: the Spokane and Coeur d'Alene Railway Company, Ltd.; the Spokane Traction Company; the Spokane and Inland Railway Company; and the Spokane Terminal Company; all of which were merged into the present company on January 1, 1907. The aggregate cost of the entire property owned and operated was $15,314,357, although the book cost was somewhat in excess of this amount, due to the inclusion of discount in the plant account. The amount of actual cash invested in the property, exclusive of right of way and real estate, was $13,704,960.

The greater portion of the money invested was obtained from the sale of stock, which is rather an unusual condition in the case of railroad construction.

Paving Considered as Part of the Property.— As usual in the case of street railways, the franchises granted to the company provided that in case any streets occupied by tracks should be subsequently paved, the company would be required to pay for and maintain the paving upon its tracks and for a distance of two feet from the extreme outside of the rail. It has been contended in various appraisals made of street railway properties that such paving should not be considered as an asset of the street railway company, but should rather be regarded in the light of a tax imposed upon the company by the city. In this instance, however, the paving is included as railway property.

Unit Prices.— The estimated costs of reproducing this system, which was made as of January 1, 1911, was based upon the actual material known to have been used in its construction, while the prices used for such material, and for labor, were the prices that would prevail during the assumed construction period. It is extremely probable that there would have been but little difference in the estimated cost of reproduction, as shown, had the average price for the five preceding years been used.

Quantities.— As no estimate of the cost of reproducing the property had been prepared by the company officials, it was necessary for the engineers of the Commission to compile a statement of quantities, and to investigate and obtain the prevailing prices. The statement of grading quantities was, in the main, obtained from the final estimates as allowed the different contractors, and such estimates were again checked with vouchers in existence in the Accounting Department. The statement of track material was carefully checked in the field, certain portions of the track being selected at random and checked by engineers on foot, until it was considered that the correctness of the tabulations was established. All bridges were examined and measured, poles and guys were counted, while structures of all kinds were examined and their dimensions ascertained. All electrical machinery and apparatus was inspected and listed. The only item which was difficult to ascertain was the amount of ballast. Owing to the fact that the line was never completely ballasted, the work having been done piecemeal, it was an extremely hard matter to ascertain the amount of ballast under the ties.

Labor Costs.— As is usually the case, obtaining representative labor costs presented the greatest difficulty. Obtaining prices of material involves quite an amount of work, but arriving at proper labor charges calls for a great deal more. Owing to the fact that this road was but recently constructed, it was felt that the cost of reproduction should certainly not depart in any marked degree from the actual cost. It was, therefore, decided to obtain the labor costs altogether from the records of the company, if possible. To this end, hundreds of work records compiled by the Engineering Department, and bearing on work recently done, were examined, in

order to ascertain what different classes of work were costing the company; so that in the end practically all of the labor costs used in connection with the overhead construction were obtained from these reports. It should not be inferred that the actual construction costs were taken in all cases. For example, the grading on the Opportunity Line, which was done by company forces, actually cost 50 cts. per cu. yd. for gravel excavation, while for the purposes of the estimate, 30 cts. per cu. yd. was deemed a fair price. The average daily wage of laborers engaged in setting poles on the different divisions during the construction period was $1.75 per day. In the estimate of reproduction the Union scale of $2.50 per day was used.

Comparison of Actual Cost With Appraised Value.— The estimated cost of reproducing the property (exclusive of real estate and right of way), has almost invariably been less than the actual cost. In this case, an extensive investigation was conducted concerning the comparative present and past costs of labor and material, in order to be properly prepared for cross examination.

Among other things it was found that the price of copper at the date of appraisal was much lower than when the road was built. In all probability, the copper used by the company was purchased on an average base price of at least 20 cts. for ingot copper, while the base price used in the estimate of reproduction was only 13 cts. The price of car bodies and trucks was found to have advanced approximately 10% in the last five years. The price of poles had decreased slightly, while there had been no appreciable changes in the cost of electrical machinery or in the price of labor.

Overhead or Loading Charges.— The estimated cost of reproduction included an allowance of 10% for Engineering, Supervision and Organization Expense; 5% interest during the construction period; 5% for contingencies; and 3.75% for brokers' fees. In addition to this, there was included the sum of $500,000 to cover the item of Stores and Working Capital.

Cars.— It should be noted that the percentage items of Engineering, Supervision and Organization Expense, Interest During Construction and Contingencies, do not cover expenditures for equipment. This was due to the fact that the allowance for Engineering, Supervision and Organization Expense was in a manner based upon percentages obtained by arriving at the actual ratio borne to the cost of construction, exclusive of equipment, by these three items. Further, the equipment would probably not be delivered and paid for until near the close of the construction period; hence, no investment would be required until that time and the expenditures for interest would not be necessary. The cost of reproducing the equipment was based upon actual contract prices, which are so clean cut and so complete in every detail, that it was considered unnecessary to allow contingencies for this item. Brokers' Fees, however, cover expenditures for every other item included in the estimated cost of reproduction.

Summary.— The table shows the cost of reproduction by accounts and by states.

TABLE I. COST BY STATES

(Equipment included.)

	Washington	Idaho	Total
Inland division	$ 6,550,350	$ 466,572	$ 7,016,922
Coeur d'Alene division	1,278,708	1,094,260	2,372,968
Traction division	2,027,405	....	2,027,405
Joint tracks and terminals	763,930	....	763,930
Nine Mile power plant	1,498,490	....	1,498,490
Nine Mile tran. lines	65,404	....	65,404
Commercial power lines	116,343	60,498	176,841
	$12,300,630	$1,621,330	$13,921,960

COST OF REPRODUCTION, ENTIRE SYSTEM, BY ACCOUNTS

	Total
Grading	$ 1,768,578
Ballast	280,475
Ties	291,925
Rails, fast. and joints	1,508,413
Frogs and switches	151,675
Paving	254,475
Track laying and surf.	326,241
Roadway tools	6,600
Tunnels	51,626
Bridges, trestles and culverts	670,065
Crossings, etc.	117,126
Interlocking, etc.	22,111
Tel. and tel. lines	30,344
Poles and fixtures	341,616
Transmission system	179,727
Distribution system	465,557
Dams and power houses	869,500
Substation buildings	161,249
General office buildings	125,400
Shops and car houses	151,472
Stations, etc.	149,691
Water stations	4,800
Docks and wharves	32,210
Power plant equipment	270,000
Substation equipment	774,309
Shop equipment	41,000
Park and resort property	83,167
Teams and vehicles	4,215
Eng., supt. and org. exp.	913,356
Interest during construction	502,346
Contingencies	527,463
Stores and working capital	500,000
Steam locomotives	35,000
Electric locomotives	276,000
Passenger train cars	631,500
Freight train cars	409,425
Traction cars	457,850
Work equipment	20,000
Floating equipment	11,000
Misc. equipment	1,250
Brokers' fees	503,203
Totals	$13,921,960

Valuation of the Puget Sound Electric Railway. The following is abstracted from an article by Henry L. Gray in Engineering and Contracting, May 25, 1910.

The Puget Sound Electric owns and operates a line between the

cities of Seattle and Tacoma, and in addition, branch lines extending to Renton, a smaller city having extensive coal mining and ceramic industries; the Orting branch extending to Puyallup, the center of a large berry and fruit district, and a short feeder serving the packing house district of Tacoma, known as the Tide Flats line. The company also owns the East P. Street line in the city of Tacoma, and what is known as the old Puyallup line, but as both of the latter are leased and operated by the Tacoma Railway & Power Co., they are not considered part of the system. The company also owns several lighting franchises in cities along the line, as well as a large tract of timber land, and a saw mill which is operated for commercial purposes. This road, as well as the street railway systems of Seattle and Tacoma, is owned by Stone and Webster, with their associates, being managed by the former.

The main line extends from the city limits of Seattle to the city limits of Tacoma, a distance of 32.01 miles, entrance to the business centers of the cities being obtained over the tracks of the Tacoma Railway & Power Co. and the Seattle Electric Co. The track mileage owned and operated was as follows on June 30, 1909:

	Miles
Main track:	
First track, main line	32.01
Second track, main line	10.91
Orting branch	6.94
Renton branch	2.96
Tide Flats line	0.58
Total main track	53 40
Sidings, etc.:	
On main line	8.24
On Orting branch	0.60
On Renton branch	1.38
On Tide Flats line	0.13
Total sidings, etc.	10.35
Grand total	63.75

On the main line, between Seattle and Tacoma, consisting of 42.92 miles of first and second track, there are 7.30 miles of curved track. The total ascent is 356 ft., and the total descent is 409 ft. About 7 miles of the line was built on trestles.

The main line and Renton branch were built in 1902, the Tide Flats line in 1904, the Orting branch in 1908, and the second track over a period from 1904 to 1909. The population of Seattle is about 250,000, Tacoma, 150,000, while the country tributary to the line contains approximately 15,000 people, many of whom own small tracts adjacent to towns, working in Seattle and Tacoma, going to and from their work each day. All of the larger towns on this road are also served by two steam roads charging 3 cts. per mile, while Seattle and Tacoma have boat service at intervals of two hours, the boat fare being 35 cts. one way or 50 cts. for the round trip.

The land became quite valuable for small fruit raising, truck

gardening and dairying, the values ranging from $100 to $1,000 per acre. Real estate firms acquired large tracts and disposed of them in smaller tracts of from one to five acres, selling them on monthly payments to clerks and artisans employed in the terminal cities, whose intention it was to use their spare time building up small vegetable or berry gardens and ultimately devoting their entire time to such work.

As in the case of the valuation of the steam roads, finding the actual cost consumed the major portion of the time. It is an astonishing fact that, with one exception, there has never been a railroad under investigation by the Railroad Commission of Washington which could readily give the cost of construction, and, in many cases, little or no record of such cost existed. Fortunately, however, there are other records besides books or company records, and this important item has invariably been determined to the satisfaction of all concerned. In the present case the property account represented only the face value of stocks and bonds which had been issued in payment for the construction of the road, the records of the original construction being missing from the general offices in Tacoma and there being some doubt as to their existence. Every vault and out of the way place in the Tacoma office was carefully explored. Several old letter files, found in a dark corner of an unused vault, proved to be mines of information, one of them containing a complete itemized statement of the cost of the road at the time it was turned over to the operating department. The rest was easy, and was made even more so by the arrival of a similar statement from the Boston office, checking the statement found in Tacoma.

Similar conditions existed in the engineering department. Owing to the general scheme of construction, which contemplated payment for work with stocks and bonds, no quantities or final estimates were available. A thorough examination was made of the entire line, cross sections were taken where the profile could not be relied upon to indicate the grading quantities; material in cuts was classified, buildings and bridges measured up and examined, and in short, all data possble were compiled in the field. The existing office records were compared with the field notes and a fairly close check resulted. The grading quantities were obtained partly from a profile estimate and partly from the cross sections taken in the field. The material in the cuts was classified according to the field inspection and the over-haul computed from the profile. The statement of track material was taken from the office records, which checked the field notes closely. The bridge and building lists were compiled from the field notes, as the office records were not complete. Ballast was the subject of much discussion and was a source of disagreement. An itemized statement of the transmission and distribution systems prepared by the Superintendent of Power was of great assistance, checking the field notes closely. The Master Mechanic provided a list of equipment which was of great aid. Except in the case of grading and ballast, no difference existed

between the statements of quantities compiled by the engineers of the railway and those of the Commission, while every disposition was shown to aid the latter.

Proceeding upon the theory that what a thing cost is at least good evidence of what it might cost again, the records of the auditor's office were closely examined and all improvement requisitions scrutinized. The purchasing agent was in great demand, for while the engineers engaged in this work were, from much experience, familiar with the cost of material, yet prices fluctuate and it is frequently the case that a small road is compelled to pay more for its supplies than a larger one, and these things should be taken into consideration. A great deal of information was obtained from the old letter files previously referred to; for instance, they contained an itemized statement of the cost of track laying. Officers of the company were freely consulted, as it was the desire to compile a fair statement of quantities involved, and to show the actual prices which would prevail should the road be reconstructed.

The cost of reproducing the right of way and real estate was arrived at in exactly the same manner as in a condemnation suit. Lists were prepared, with the necessary maps, and furnished to real estate experts, who walked over the line valuing each piece of right of way on the basis of the value of the contiguous property, regardless of the fact that the presence of the railroad lent value to such property. These lists, with the allotted value shown thereon, were introduced as evidence. Testimony was then taken as to the value of such property for railroad purposes, which showed clearly that it was necessary to multiply the land value by a factor, in order to arrive at the cost of repurchasing the property for railroad purposes. This factor ranged from 1 to 5, depending altogether upon the location and value, city property requiring a factor of about 1½, first-class farm property, about 2½, while land which was practically worthless, required a factor nearer 5. The smaller the value of the land, the higher the factor. After considering the testimony of the experts on both sides, and reviewing possible consequential damages, the cost of reproducing the right of way and real estate was fixed. As the road owns very little city property, practically all of the sum shown as the cost of reproduction of right of way and real estate, represents the former, so that the average cost of reproduction per acre was about $1,250. As the average value of the contiguous property was about $500, the average factor was approximately 2½. It is a commendable fact that the estimate made by the railroad officials was smaller than that made by the real estate experts employed by the Commission.

During the appraisal of the steam roads, of the state, it was established that 3½% of the total cost of construction was an ample allowance for engineering, and that 1 per cent. of such cost was sufficient to cover expenditures for legal and general expense. But as the construction of this road presented no difficult engineering problems, it was considered that, in this case, 3% would be a liberal allowance for engineering, but it developed that in addition

to the sum expended for local engineering, Stone and Webster had received an additional 10 per cent. as an engineering commission. The matter of an engineering commission had not presented itself before, the steam roads, who were not supposed to over-look anything, contending for a total allowance of only 5% for engineering. It was a well known fact, however, that such a charge was by no means unusual, but it was apparent that such a commission was not a strictly "engineering commission," but really covered the cost incident to purchasing supplies and expenses of management during construction, and was in a way a fee for procuring the funds for the construction, so that the only doubt was under which head to include such commission, which was finally shown under the account "Fiscal and Physical Supervision and Management." In accordance with the usual custom, 1% was allowed for "Legal and General Expense" and 5 per cent. for "Contingencies." The latter item was a source of much contention, the railway claiming that 10% should be allowed. It was held, however, that, as the quantities were known, and as prices were very liberal and had been fixed after due consideration of the cost, and that as allowance had been made for extra work, and for other items of expense which could not be estimated, many of the contingencies which might be met with had been taken care of in the estimate, so that 5% was a fair allowance in such a case.

The amount of cash and the approximate value of the stores on hand at the time of the inquiry were allowed under the account "Stores and Working Capital," the same being approximately 10% of the estimated cost of reproduction, which was the percentage recommended by the writer. Interest at 5% per annum was allowed, it being considered that 1½ yrs. would be required in which to construct the road. This item amounted to 7½% on the cost of reproducing the right of way and one-half of this, or 3¾% on the remaining construction items, as the sum invested in the latter would only be required for an average of one-half the time. The lighting system, both physically and financially, was so closely interwoven with the railway, that it was deemed inexpedient to attempt to separate them, so it was allowed as representing part of the cost of reproducing the system. The locomotives and motor car had been purchased second hand, hence the cost of reproducing them second hand was allowed, rather than the cost of reproducing them new.

Probably the most thoroughly contested point was "Discount," the railroad engineers contending that 10% of the total estimated expenditure should be allowed to cover this item, and should be included in the cost of reproduction. It was shown that the bonds had sold at 85 while stock was given with the bonds as a bonus, but the Commission held that when a railroad was built entire from the sale of bonds, it ceased to be an investment, and became a speculation; that in such a case it was doubtful if the stock was entitled to *any* return. Testimony was introduced showing that if 25% of the stock of a legitimate enterprise was paid up; that the bonds would without question sell at par, while the entire expense

in connection with the sale of such bonds would not exceed 5%; hence 5% of 75% of the total estimated expenditures was allowed as "Broker's Fees."

The depreciated value was arrived at by the combined use of mortality tables and by field inspection, and represents the cost of reproduction less depreciation. The cost of reproducing the different items, for example, pile bridges, was determined, and the average life and age being known, the depreciation in dollars was easily obtained. The possible scrap value of material was taken into account, as in the case of rails, which were assigned a life of 20 yrs., with a scrap value of 40%, or an annual depreciation of 3%. Trolley wire was assigned a life of 10 yrs., during which time it was considered that it would wear 25%, having a scrap value of 60%, hence the actual scrap value would be only 45%, and the annual depreciation 5½%. Substation equipment was carefully inspected, and found to be practically new after seven years' use, but as obsolescence and inadequacy are forms of depreciation and may be expected to play a part, an annual depreciation of 5% was allowed for this item.

The actual original cost of the road was found to be $3,647,018, which included $407,234, advanced for working capital and $305,929 of discount, leaving a net cost of $2,933,855.

In fixing the cost of reproduction the Railroad Commission regards its engineer simply in the light of a witness, and is not bound by his testimony, hence it is not uncommon for quantities or prices to be increased or decreased after hearing to the testimony of the defendant's witnesses. Many questions are simply matter of opinion and depend upon the point of view. The following table includes all items and shows the total estimated cost of reproduction and depreciated value as made by the engineers and the sum fixed by the Commission in their findings:

	Engineer of the commission	Engineer railroad company	Allowed by railroad commission
Cost of reproduction	$3,943,550	$5,123,173	$4,157,558
Depreciated value	3,352,463	4,424,395	3,598,232

COST OF REPRODUCING NEW THE PUGET SOUND ELECTRIC RY.

(June 30, 1909.)

1. Right of way and real estate	$917,733
2. Engineering and superintendence:	
3% of items 4 to 25	53,336
3. Fiscal and physical supervision:	
Amount expended	186,955
4. Grading:	
610,000 cu. yds. common excava., at $0.25	152,500
47,500 cu. yds. common long haul, at $0.095............	4,512
150,000 cu. yds. hard pan, at $0.45	67,500
1,150 cu. yds. solid rock, at $1.10	1,265
700,000 cu. yds. overhaul 100 ft. at $0.01	7,000

133 acres clearing at $60.00	$ 7,980
580 stations grubbing at $15.00	8,700
580 stations grubbing at $15.00	8,700
200 dangerous trees cut at $2.00	400
Ditching and miscel.	2,000
Total grading	$251,857

5. Ballast:

46.35 miles gravel at $1,100.00	$ 50,985

6. Ties:

157,877 ties (6 by 8 by 8) at $0.35	$ 55,207
16,646 ties (6 by 8 by 9) at $0.40	6,658
Total ties	$ 61,865

7. Rails, fastenings and joints:

5,292.8 tons 30-ft. steel rails at $39.50	$209,066
1,409.1 tons 60-ft. steel rails at $41.50	58,478
14,584 Weber joints (60 and 70-lb.) at $2.50	36,460
1,327 American continuous joints at $2.15	2,853
106,596 lb. angle bars (56 and 60-lb.) at $0.03	3,198
25,240 lb. fish plates (30, 40 and 42-lb.) at $0.025	631
10,304 lb. track bolts (¾ by 3¾) at $0.0325	85
2,574 lb. track bolts (⅝ by 2½) at $0.325	85
369,986 lb. spikes (9/16 by 5½) at $0.0225	8,325
2,000 braces at $0.10	200
3,010 lin. ft. guard rail at $0.50	1,505
Total rails, fastenings and joints	$321,136

8. Frogs and switches:

66 spring frogs (70-lb.) at $50.00	$ 3,300
22 rigid frogs (70-lb.) at $30.00	660
22 rigid frogs (60-lb.) at $30.00	660
16 rigid frogs (50-lb.) at $25.00	400
13 rigid frogs (40-lb.) at $20.00	260
72 split switches complete (70-lb.) at $40.00	2,880
12 split switches complete (60-lb.) at $35.00	420
1 split switch complete (50-lb.) at $25.00	25
6 split switches complete (40-lb.) at $15.00	90
8 sets head chairs at $4.00	32
8 sets tie bars at $10.00	80
59 high stands at $25.00	1,475
2 low stands at $18.00	36
30 ground throws at $10.00	300
139 pairs guard rails at $10.00	1,390
47 loose tongue switches at $50.00	2,350
3 derails at $6.00	18
59 switch lamps at $5.00	295
61 switch locks at $0.50	31
5 crossing frogs at $300.00	1,500
Total frogs and switches	$ 16,201

9. Paving:

1,096,630 ft. B. M. fir planking at $16.00	$ 17,546
140 kegs wire spokes at $3.00	420
40,000 ft. B. M. wood filler at $24.00	960
600 cu. yd. broken stone at $1.50	900
Total paving	$ 19,826

10. Track laying and surfacing:

63.75 miles track at $700.00	$ 44,625
139 frogs and switches placed at $25.00	3,475
5 crossing frogs placed at $25.00	125
Total track laying and surfacing	$ 48,225

11. Tunnels:

180 lin. ft. timber lined at $65.00	$ 11,700

12. Bridges, trestles and culverts:

210 lin. ft. span bow steel truss (on cylinder piers) at $100.00	$ 21.000
72 lin. ft. span deck girder (pile abuts.) at $50.00	3,600
60 lin. ft. span I-beam (pile abuts.) at $30.00	1,800
220 lin. ft. span combination (2 spans of 110 ft. cylinder piers) at $55.00	12,100
150 lin. ft. span combination (pile abuts.) at $45.00	6,750
150 lin. ft. span combination (cylinder piers) at $47.00	7,050
200 lin. ft. span Howe truss draw (on pile crib) at $65.00	13,000
190 lin. ft. span Howe truss draw (on pile crib) at $65.00	12,350
100 lin. ft. span Pony Howe truss (pile abuts.) at $30.00	3,000
80 lin. ft. span Pony Howe truss (pile abuts.) at $25.00	2,000
87 lin. ft. span Pony Howe truss (pile abuts.) at $27.00	2,349
60 lin. ft. span Pony Howe truss (pile abuts.) at $20.00	1,200
361,612 lin. ft. piles in place at $0.25	90,403
39,256 lin. ft. piles cut off at $0.10	3,925
4,889,386 ft. B. M. timber in trestles at $28.00	136.903
166,451 lb. wrt. iron in trestles at $0.035	5,826
121,515 lb. cast iron in trestles at $0.035	3,645
150 lin. ft. of 12-in. vitrified pipe at $1.00	150
272 lin. ft. of 14-in. vitrified pipe at $1.25	340
659 lin. ft. of 15-in. vitrified pipe at $1.35	889
802 lin. ft. of 16-in. vitrified pipe at $1.50	1,203
1,364 lin. ft. of 18-in. vitrified pipe at $1.75	2,387
42 lin. ft. of 24-in. vitrified pipe at $2.90	122
8,382 ft. B. M. timber in wooden boxes at $25.00	210
8,283 lin. ft. logs in culverts at $0.12	994
River bank protection, Black River, cost	4,857
Fill and dam, Puyallup River, cost	4,000
2,000 cu. yd. riprap at $1.25	2,500
Total bridges, trestles and culverts	$344,553

13. Crossings, fences, cattle guards and signs:

82,615 ft. B. M. timber in crossings at $20.00	$ 1,652
146,233 ft. B. M. timber in inclines to grade crossings at $27.00	3,948
1,074 lb. wrt. iron, in inclines, at $0.035	38
210 lb. cast iron, in inclines, at $0.035	6
30 kegs wire spikes, in inclines, at $3.00	90
9,650 ft. B. M. timber in farm crossing inclines, at $25.00	241
3 kegs wire spikes in ditto at $3.00	9
54 single miles board fence at $450.00	24,300
8 single miles comb. woven and wire fence at $300.00	2,400
1,960 lin. ft. tight board fence at $0.56	1,097
150 board gates at $3.00	450
82 cattle guards, trackman, at $25.00	2,050
207 cattle guards, Bartlett, at $20.00	4,140
13 danger signs at $2.00	26
196 warning signs at $2.00	392
28 railroad crossing signs at $5.00	140
3 station signs, single, at $10.00	30
35 electric rail signs at $3.00	105
38 "stop, look, listen" signs at $1.00	28
4 yard limit signs at $4.00	16
3 city limit signs at $1.00	3

31	whistle posts at $1.00	$ 31
19	S. posts at $1.00	19
	Total crossings, fences, etc.	$ 41,508
14.	Interlocking and signal apparatus:	
38	platform stop signals at $8.00	$ 304
3	train order signals at $20.00	60
2	block light sets at $275.00	550
	Total interlocking and signal	$ 914
15.	Telegraph and telephone lines:	
53	cedar poles, 45-ft., at $4.50	$ 238
66	cedar poles, 40-ft., at $3.80	251
1,675	cross arms (4 pin) with hardware at $0.80	1,340
316	cross arms (6 pin) with hardware at $1.00	316
15,312	lb. telephone wire No. 10 copper at $0.18	2,756
13,300	lb. telegraph wire No. 9 bare iron at $0.06	798
1,750	lb. telegraph wire No. 10 W. P. at $0.07	122
5,886	double petticoat insulators with pins at $0.07	412
11	telegraph keys at $1.05	12
10	telegraph sounders at $5.25	52
14	telegraph relays at $4.20	59
6	telegraph box relays at $4.25	25
12	telegraph cut outs at $1.25	15
	Telephone switchboard, cost	275
	Telephone storage battery, cost	25
	Labor	2,500
	Total telegraph and telephone lines	$ 9,196
16.	Poles and fixtures:	
1,544	transmission poles, 50-ft, cedar at $5.50	$ 8,492
28	transmission poles, 70-ft. cedar, at $11.25	315
603	trolley poles, 30-ft., at $2.55	1,538
324	trolley poles, 40-ft., at $3.80	1,231
1,635	transmission cross arms, 2 pin, with hardware, at $0.70	1,144
1,572	feeder cross arms, 4 pin, with hardware, at $0.80	1,258
316	feeder cross arms, 6 pin, with hardware, at $1.00	316
57	guy wire clamps, galv., 3-bolt, at $0.12	7
14	line anchor clamps, mal. galv., at $0.50	7
82	anchor rods at $0.50	41
	Labor	14,979
	Total poles and fixtures	$ 29,328
17.	Transmission System:	
25,050	lb. transmission line wire, bore 1-0, at $0.18	$ 4,509
6,516	lb. transmission line wire, bore No. 1, at $0.18	1,172
54,534	lb. transmission line wire, bore No. 4, at $0.18	9,816
3,425	insulator pine at $0.40	1,370
1,607	pole brackets at $0.40	643
5,025	insulators at $1.50	7,538
	Miscel. material	500
	Labor	4,000
	Total transmission system	$ 29,548
18.	Distribution System:	
72	cut out switches, 50 ampere Q. B., at $9.00	$ 648
66,598	lb. 3d rail crossing cables W. P. 500 M. C. M. at $0.18	11,888
2,353	lb. 3d rail crossing cables W. P. 300 M. C. M. at $0.18	424

765	lb. 3d rail feed taps W. P. 500 M. C. M. at $0.18...$	138
371	lb. 3d rail feed taps W. P. 300 M. C. M. at $0.18....	67
300	lb. 3d rail feed taps W. P. 100 M. C. M. at $0.18...	54
74,470	lb. overhead feeders, bare, 500 M. C. M. at $0.18..	13,405
137,529	lb. overhead feeders, bare, 300 M. C. M. at $0.18....	24,755
9,119	lb. overhead feeders, W. P., 500 M. C. M. at $0.18..	1,641
4,787	lb. overhead grounds, W. P., 500 M. C. M. at $0.18..	862
900	lb. overhead grounds, W. P., 300 M. C. M. at $0.18	162
613	lb. cross bars, frogs and switch jumpers, W. P. 500 M. C. M. at $0.18	110
1,142	lb. ditto, W. P., 300 M. C. M. at $0.18.............	206
335	lb. ditto, W. P., 4-0 M. C. M. at $0.18.............	60
16,900	running rail bonds main line at $0.50...............	8,450
1,200	running rail bonds 212 B. B. at $0.44	528
304	running rail bonds "A" 4–0 at $0.37..............	112
6,745	third rail bonds at $1.28	8,634
16,863	third rail insulators at $0.88	14,839
2,935	tons third rail (30-ft., 100-lb.) at $39.50...........	115,933
252	third rail noses at $2.00	504
504	nose fish plates at $0.70..........................	352
12,800	third rail fish plates at $0.24	3,072
32,000	lb. third rail bolts at $0.03	960
55,432	lb. trolley wire 4-0 at $0.18	9,978
11,290	lb. trolley wire 2-0 at $0.18	2,032
4,880	lb. trolley wire 1-0 at 0.18	878
38,000	ft. Siemens-Martens steel cable, 7/16-in., at 0.0315 ..	1,197
2,000	ft. Siemens-Martens steel cable, 3/8-in., at 0.027	54
3,000	ft. Siemens-Martens steel cable, 1/4-in., at 0.025	75
16,000	ft. signal strand, 1/4-in., at 0.0083	133
32,650	ft. signal strand, 5/16-in., at 0.011	359
1,000	ft. signal strand, 3/8 in-., at 0.013	13
1,639	eye bolts at 0.12	197
1,542	wood strain insulators, G. E., at 0.23	355
80	wood strain insulators, home made, at 0.25	20
240	single curve hangers at 0.51	122
180	double curve hangers at 0.57	85
588	straight line hangers at 0.51	300
1,888	cable insulators with pine at 0.23	434
659	ears, 2-0, at 0.30	198
165	ears, single 0, at 0.25	41
171	ears, 4-0, at 0.35	60
35	trolley frogs at 3.50	123
339	T bar pole brackets, at 2.50	848
16	Richmond flexible pole brackets, at 2.50	40
53	steady bar bracket attachments at 3.40	180
3,997	messenger clips, 5/8-in., mal. galv., at 0.06	240
3,956	Detroit "Form 2" clamps, 5/8-in., mal. galv., at $0.10	360
46	Detroit "Form 5" clamps, 5/8-in. mal. galv., at 0.20	9
46	strain collars, 5/8-in., at 0.038	2
645	steel hanger rods, galv., 5/8 by 13 1/2 at 0.03	19
18	steel hanger rods, galv., 5/8 by 13 1/2 at 0.075	1
645	hangers, galv., 5/8 byp 4, 120 ft. span, 0.032	21
616	hangers, galv., 5/8 by 5 1/2, 120 ft. span, at 0.038	23
645	hangers, galv., 5/8 by 7 1/2, 120 ft. span, at 0.045	29
645	hangers, galv., 5/8 by 9 3/4, 120 ft. span, at 0.053	34
645	hangers, galv., 5/8 by 12 3/4, 120 ft. span, at 0.066 ...	43
29	hangers, galv., 5/8 by 5 1/2, 120 ft. span, at 0.047 ...	1
31	hangers, galv., 5/8 by 7 1/2, 100 ft. span, at 0.053	2
16	hangers, galv., 5/8 by 8 3/4, 100 ft. span, at 0.059	1
16	hangers, galv., 5/8 by 10 1/2, 100 ft. span, at 0.065 ...	1
16	hangers, galv., 5/8 by 13 1/2, 100 ft. span, at 0.075 ...	1
18	hangers, galv., 5/8 by 11 3/4, 60 ft. span, at 0.07	1
18	hangers, galv., 5/8 by 12 3/4, 60 ft. span, at 0.073	1
92	wood brake strain insulators, 1 1/4 by 14, at 0.18	17
18	Crosby clips, 3/8 in., at 0.08	1
57	Crosby clips, 7/16 in., at 0.09	5
15	trolley wire connections, brass, 2 by 7/8, 4-0 grvd., at 1.10	17

339 porcelain messenger insulators, 10,000 v., 1¾ pin hole, at 0.15	$ 54
4 overhead switches at 12.50	50
100,165 ft. B. M. timber, cable boxes, at 10.00	1,002
Miscellaneous material	500
Labor	25,000
Total distribution system	$253,065

19. Substation Buildings:

122,708 cu. ft. brick bldg., at Kent, at 0.125	$ 15,338
28,940 cu. ft. frame bldg., at Kent., at 0.10	2,894
87,030 cu. ft. brick bldg., at Milton, at 0.125	10,879
28,940 cu. ft. frame bldg., at Milton, at 0.10	2,894
84,820 cu. ft. brick bldg., at Puyallop, at 0.125	10,602
Total substation buildings	$ 42,607

20. Shops and Car Houses:

8,568 sq. ft. corrugated iron car sheds, at 0.45	$ 3,855
19,248 sq. ft. frame car sheds, at 0.50	9,624
2 sets track scales, at 1,300.00	2,600
Total shops and car houses	$ 16,080

21. Stations and Miscellaneous Buildings:

Brick and frame station, Tacoma	$ 4,000
2,850 sq. ft. frame station, 2 story, at 2.00	5,700
5,728 sq. ft. frame stations, bungalow type, at 1.25	7,160
8,318 sq. ft. frame stations, old standard, at 1.00	8,318
108 sq. ft. open sheds, at 0.50	54
2,396 sq. ft. frame freight sheds, at 0.90	2,156
1,060 sq. ft. corrugated iron freight sheds, at 0.50	530
478 sq. ft. miscellaneous frame sheds, at 0.50	239
216 sq. ft. telephone shacks, at 0.50	108
306 sq. ft. tool sheds, at 0.50	153
372 sq. ft. section house, at 0.50	186
64,111 sq. ft. low passenger platforms, at 0.10	6,411
5,875 sq. ft. high passenger platforms, at 0.15	881
4,562 sq. ft. freight platforms, at 0.15	684
3,909 sq. ft. milk platforms, at 0.20	782
8 water closets, at 50.00	400
Total stations and miscel. bldgs.	$ 44,211

22. Substation Equipment:

3 lightning arresters, 50,000 volt, 3 pole, at 621.00	$ 1,863
5 oil switches, 50,000 volt, type H, at 1,600.00	8,000
212 Thomas insulators, 50,000 volt, at 1.85	392
36 disconnecting switches, 50,000 volt, at 41.50	1,494
494 lb. bare copper wire, at 0.18	89
7 oil cooled transformers, 200 kw., at 2,300.00	16,100
4 oil cooled transformers, 180 kw., at 1,000.00	4,000
4 current transformers, 50,000 volt, at 150.00	600
3 inducting motor generator sets, 300 kw., with non-automatic, double pole oil switches, 2,300 volts and 600 volt, generator panels (1 slate and 2 marble), at 8,500.00	25,500
2 automatic oil switches, 4 pole st. 300 ampere with slate slabs and 2 current transformers, at 140.00	280
3 H. E. Ind. volt meters, with potential transformers, at 85.00	255
6 railway feeder panels, marble, at 200.00	1,200
1 lightning panel, marble 16 in.	100
1 lightning panel, marble 24 in.	300
2 C. R. regulators at 315.00	630
2 booster transformers, 3 kw., at 47.50	95
2 booster transformers, 5 kw., at 66.50	133

1 polyphase recording watt meter, 300 amp., and two 200 watt potential transformers, and 2 current transformers 300-5 amp.	$ 200
1 T. R. watt meter, 800 amp., 600 volt	175
1 induction motor panel, 2,300 volts	290
40 ft. lead covered insulated cable, 500 M. C. M., at 0.91	36
400 ft. lead covered insulated cable, No. 2, at 0.90	360
80 ft. lead covered insulated cable, No. 4, at 0.30	24
147 ft. weather proof cable, 800 M. C. M., at 0.60	86
509 ft. weather proof cable, 500 M. C. M., at 0.45	229
540 ft. rubber covered cable, No. 2, at 0.08	40
26 ft. rubber covered cable, 500 M. C. M., at 0.65	17
2 50,000 volt, 150 to 50 current transformers, at 300 ..	600
1 motor panel, 24 in. marble, 2,300 volt, with automatic oil switch, 300 amp., 4 pole st	290
1 T. R. watt meter, polyphase, 300 amp., with 2,300 to 5 current transformers	200
1 T. R. watt meter, 800 amp., 600 volt	175
5 oil switches, 3 pole, 30,000 volts, at 400	2,000
9 disconnecting switches, 30,000 volts, at 20	180
30 Westinghouse air brake jacks and slabs, at 8	240
30 marble barriers for same, at 30	900
3 lightning arresters, 3 pole, 30,000 volts, at 100	300
3 generator panels, slate 16 in., at 200.00	600
3 slate slabs and switch handles, at 20.00	60
6 feeder panels, 16 in. plate, at 50	300
1 slate slab with synchronizer	55
2 front connected feeder switches, at 20.00	40
10 current transformers, 30,000 volt, at 125	1,250
8 potential transformers, at 150	1,200
1 compensator for 180 kw. transformers, 17.5 kw.	275
318 lb. bare copper wire, at 0.18	57
Miscellaneous equipment	500
3 air compressors and receiving tanks with 4 h.p. motors, at 300	900
Labor of installing transformers and generators in 3 substations	3,400
3 storage battery sets consisting of chloride accumulators (288 cells of 15 plates per cell; 288 cells of 17 plates per cell; 288 cells of 17 negative plates per cell); 428 ft. lead covered rubber insulated cable, 3 booster sets, 35 kw.; 6 marble battery panels; including freight and installation	106,149
Total substation equipment	$182,159

23. Shop Equipment:

1 sharper, 20 in.	$ 250
1 radial drill, 24 in.	150
1 metal lathe, 20 in. by 12 ft.	570
Miscellaneous hand tools	30
Total shop equipment	$ 1,000

24. Water Stations:

2 box tanks, 6 by 7 by 16 ft., at 100.00	$ 200
Pumping plant and pipe	200
Total water stations	$ 400

25. Engineering Instruments and roadway tools ...... $ 1,500

26. Legal and General Expense:

1% of items 4 to 25 .... $ 17,779

27. Interest During Construction:

7.5% of item 1, and 3.75% of items 2 to 26 .... $145,181

28. Contingencies:	
5% of all above items, exclusive of items 1, 3 and part of 27 (interest on right of way)	$ 96,266
29. Stores and Working Capital:	
Cash and stores on hand June 30, 1909	$300,000
Total construction	$3,495,154
30. Cars (exclusive of electric equip.):	
9 combination baggage and coach, at 6,206.00	$ 55,860
5 passenger cars, at 4,160	20,530
4 motor trailers, at 5,500	21,000
11 trailers, at 5,025.50	55,280
4 observation cars, at 10,290	41,160
4 race track cars, at 2,625	10,500
22 box cars, freight, at 729.50	16,050
25 hopper cars, freight, at 675	16,875
14 gondola cars, freight, at 668	9,350
97 flat cars, freight, at 558	54,126
2 freight motor cars, box type, at 3,000	6,000
3 freight motor cars, cab type, at 2,500	7,500
1 derrick car	1,200
1 pile driver	1,500
1 steam shovel	10,000
Total cars, etc.	$326,931
31. Locomotives:	
1 Baldwin, No. 1 steam, second hand	$ 2,500
1 Manchester, No. 2 steam, second hand	2,500
1 Hinkley, No. 3 steam, second hand	2,500
Total locomotives	$ 7,500
32. Electric Equipment of Cars:	
8 General Electric No. 66, 4 motor equipments, at 7,575	$ 60,600
4 General Electric No. 66, 2 motor equipments, at 4,000	16,000
2 General Electric No. 205, 4 motor equipments, at 7,000	14,000
4 General Electric No. 90, 4 motor equipments, at 3,200	12,800
4 Westinghouse Electric No. 49, 2 motor equipments, at 1,200	4,800
5 General Electric No. 66, freight motor equipment, at 7,500	37,500
Total electric equipment of cars	$145,700
33. Miscellaneous Equipment:	
1 Packard touring car, second hand	$ 2,000
Total equipment (items 30 to 33)	$ 482,131
Total construction and equipment	$3,977,285
34. Lighting system	$ 30,000
35. Brokerage Fees:	
5% to 75% of above	$ 150,273
Grand total	$4,157,558

Item 35 was allowed on the assumption that if bankers had to provide only 75% of the cash used in construction and equipment

(the balance being furnished by the promoters), a reasonable brokerage fee would be 5% of the cash thus secured.

Item 31, "Locomotives," relates to locomotives worth $8,000 new, but purchased second hand.

DEPRECIATED VALUE OF THE PUGET SOUND ELECTRIC RY.

(June 30, 1909.)

1. Right of way and real estate	$ 917,775
2. Engineering and superintendence	53,336
3. Fiscal and physical supervision and management	186,955
4. Grading (incl. 10% appreciation of roadbed)	275,135
5. Ballast (15% depreciation)	43,337
6. Ties (70% depreciation)	18,559
7. Rails, fastenings and joints (15% deprec.)	272,966
8. Frogs and switches (20% deprec.)	12,961
9. Paving (50% deprec.)	9,913
10. Track laying and surfacing (30% deprec.)	33,758
11. Tunnels (5% deprec.)	11,115
12. Bridges, trestles and culverts (48% deprec.)	179,168
13. Crossings, fences, cattle guards and signs (46% deprec.)	22,414
14. Interlocking and signal apparatus (35% deprec.)	594
15. Telegraph and telephone lines (30% deprec.)	6,437
16. Poles and fixtures (43% deprec.)	16,717
17. Transmission system (no deprec.)	29,548
18. Distribution system (7% deprec.)	235,350
19. Substation buildings (10% deprec.)	38,346
20. Shops and car houses (20% deprec.)	12,864
21. Stations, waiting rooms, etc. (19% deprec.)	35,811
22. Substation equipment (27% deprec.)	132,976
23. Shop equipment (50% deprec.)	500
24. Water stations (60% deprec.)	160
25. Eng. insts. and tools (50% deprec.)	750
26. Legal and general expense	17,779
27. Interest during constr.	145,181
28. Contingencies	96,266
29. Stores and working capital	300,000
Total construction	$3,106,669
30. Cars (35% deprec.)	$ 212,505
31. Locomotives (4% deprec.)	7,200
32. Elec. equip. of cars (35% deprec.)	94,705
33. Miscel. equip. (16% deprec.)	1,680
Total equip. (items 30 to 33)	$ 316,090
Total construction and equip.	$3,422,759
34. Lighting system (16% deprec.)	25,200
35. Brokerage fees	150,273
Grand total	$3,598,232

COST OF PRODUCTION NEW PER MILE OF TRACKWAY

(53.4 miles of trackway.)

1. Right of way and real estate	$17,182
2. Engineering and superintendence	999
3. Fiscal and physical supervision	3,502
4. Grading	4,717
5. Ballast	955
6. Ties	1,159
7. Rails, fastenings and joints	6,015
8. Frogs and switches	304
9. Paving	370

10. Track laying and surfacing	$ 903
11. Tunnels	219
12. Bridges, trestles and culverts	6,454
13. Crossings, fences, cattle guards and signs	777
14. Interlocking and signal appar.	17
15. Telegraph and telephone lines	171
16. Poles and fixtures	549
17. Transmission system	554
18. Distribution system	4,741
19. Substation buildings	797
20. Shop and car houses	302
21. Stations and miscel. buildings	828
22. Substation equipment	3,411
23. Shop equipment	19
24. Water stations	7
25. Eng. insts. and roadway tools	28
26. Legal and general expense	331
27. Interest during construction	2,718
28. Contingencies	1,805
29. Stores and working capital	5,618
Total construction, etc.	$65,452
30. Cars	6,123
31. Locomotives	140
32. Electric equip. of cars	2,729
33. Miscel. equipment	37
Total equipment	$ 9,029
Total construction and equipment	$74,481
34. Lighting system	562
35. Brokerage fees	2,815
Grand total	$77,858

The above costs are per mile of trackway (53.40 miles), but since there are 63.75 miles of all tracks, or 1.194 miles of track per mile of trackway, each of the above items must be divided by 1.194 (nearly 1.2) to ascertain the cost mile of track.

An analysis of the findings of Railroad Commission indicates the following actual cost of this railway property, as taken from the accounting records of the company up to June 30, 1909:

1. Single track interurban line, up to April 1, 1903	$1,942,658
2. Subsequent expenditures on the original contract	11,064
3. Interest during construction	92,289
Total	$2,046,011
4. Additions and betterments	1,279,562
5. Working capital	407,489
Total	$3,733,062
Total	$3,713,374
Deduct construction of "P" street line	19,688
Total	$3,713,374

Item 1 includes $186,955 paid Stone and Webster for "the engineering and supervising and acting as purchasing agents and managers during construction.". Item 1 embraces the original 32.01 miles of single track line between Seattle and Tacoma, and the 2.96 miles of the Renton branch, a total of 34.97 miles of trackway.

The Commission inferred from the evidence presented, that the actual net cost of constructing and equipping the line, up to June

30, 1909, had been $2,933,864, for the Commission refused to include Items 2, 3 and 4 of the following schedule:

1. Construction and equipment	$2,933,864
2. Discounts on bonds, etc.	305,924
3. Damage due to floods after construction	44,099
4. Working capital	407,234
Total	$3,691,126

The total of this record schedule does not check exactly with the total of the first schedule just given, doubtless due to the elimination of some other items than those embraced in the "P Street line." It would appear that in the first schedule, Item 4, "Additions and Betterments," includes Item 2 of the second schedule, namely "Discounts on Bonds."

It will be noted that in the first schedule Item 3, "Interest During Construction," was not quite 5% of the construction cost.

The Commission appraised the right of way and real estate at $917,733, as of June 30, 1909. The Commission states, however, that this is $770,000 in excess of what it actually cost the railway company.

It will be observed that no power plant is included in the appraisal. The railway company purchases its power, for which it "pays $2.23 per kws. per month for the full amount of 4,750 kws. delivered on the right of way." This, we take it, is based on a 24-hr. service, and is therefore equivalent to 3.05 cts. per kw.-hr.; for $\$2.23 \times 12 = \$26.76$ per yr. and $\$26.76 \div 8{,}760$ hrs. $= 3.05$ cts. If the railway operates on a "load factor" of 50% (12 hrs. out of the 24), it follows that a power plant of $2 \times 4{,}750 = 8{,}500$ kws. would be required.

The Commission states that on June 30, 1909, the railway reported $103,367 cash on hand, and $171,257 worth of materials and supplies and bond; hence its allowance of $300,000 as a reasonable sum.

Cost of Chautauqua Interurban Railway. This interurban line, Lakewood to Mayville, N. Y., was chartered in 1903 and completed in 1904. The track mileage in 1905 was:

	Miles
Main line, first track	16.940
Branch line, " "	0.428
Total trackway	17.368
Sidings and turnouts	1.082
Total track	18.450

The cost was $494,541, distributed as follows per mile of trackway (17.368 mi.):

	Per mile
Engineering and superintendence	$ 247
Right of way	230
Real estate	3
Track and roadway construction	13,028
Electric line construction	3,428

	Per mile
Buildings	$1,825
Power plant equipment ($80,000)	4,492
Total construction	$23,253
Cars ($38,548)	2,218
Electric equipment of cars ($41,644)	2,395
Miscellaneous equipment	305
Total construction and equipment	$28,171
Organization	115
Interest and discount	192
Grand total	$28,478

The equipment was:

7 closed motor cars, 27 ton, 48 ft. at	$7,500
1 combination passenger and express, 24 ton, at	7,200
2 mail, express and freight motor cars, 20 ton, at	5,800
1 rotary snow plow, 20 ton, at	6,000
1 sweeper, 15 ton, at	1,150

The total annual car mileage was 305,874. Hence the first cost of the equipped cars was 26 cts. per annual car mile, and the first cost of the power plant equipment was 22 cts. per annual car mile. The average speed of cars was 10 miles per hr.

Comparative Cost of Various Electrical Railway Constructions and Operation. Table II, abstracted from Electrical Review, Jan. 28, 1911, was compiled by L. H. Parker, and shows the comparative cost of equipment and operation of an interurban road having a practically level track with a few easy curves, with the 6600-volt a.c. system, the 1200-volt d.c. system and the 600-volt d.c. system.

TABLE II. COSTS OF CONSTRUCTION AND OPERATION

Cost per mile of road, typical single-track interurban railway. Single 50-ft. cars, hourly headway, normal service, half-hourly headway, maximum. Catenary trolley, 80-lb. rail; schedule speed, 30 m.p.h.; maximum speed, 45 m.p.h.; stops, one in 2 miles; seating capacity of cars, 54; no baggage compartment, separate baggage and express cars.

	6600-volt a.c.	1200-volt d.c.	600-volt d.c.
Temporary construction	$250	$250	$250
Power station	2,900	2,700	2,700
Transmission line	1,000	1,000	1,000
Telephone line	100	100	100
Substations	270	1,300	1,800
Catenary trolley	2,800	2,800	2,800
Track and roadbed	17,500	17,500	17,500
Copper feeder	....	575	1,100
Rolling stock	4,300	2,800	2,400
Car house and office	1,000	1,000	1,000
Organization, eng'g., etc.	7,530	7,506	7,662
Total	$37,650	$37,531	$38,312

Cost of operation, maintenance, general expense per mile per year; total mileage of all rolling stock, 16,800; power cost, 1.5 cents per kw.-hour, including maintenance of power station:

	6600-volt a.c.	1200-volt d.c.	600-volt d.c.
Wages, trainmen	$400	$400	$400
Car house expense	50	50	50
Cost of power	700	620	620
Attendance substations	....	120	240

	6600-volt a.c.	1200-volt d.c.	600-volt d.c.
Maintenance of cars	335	250	245
Maintenance, substations	5	20	40
Maintenance, track and roadway	320	300	300
Maintenance, electric lines	60	60	60
General expense	1,000	1,000	1,000
Total	$2,870	$2,820	$2,955
Per car mile	17c	16.8c	17.6c

With 2-car train operation the initial costs were $47,219 for the 6600-volt a.c. system per mile, $46,962 for the 1200-volt d.c. system, and $48,200 for the 600-volt d.c. system. The costs of operation, maintenance and general expense were respectively figured at $3,990, $3,800 and $3,950, or 23.7 cents, 22.6 cents and 23.5 cents per train mile.

Valuation of the Chicago Consolidated Traction Co. Condensed from an article by P. J. Kealy, Engineering and Contracting, Sept. 28, 1910. The Traction Valuation Commission of Chicago, B. J. Arnold and G. W. Weston, commissioners, has recently completed an appraisal of the physical property of the above named company.

The Consolidated Traction Co. comprises seven underlying companies and operates on the north and west sides of the city; about one-third of its track mileage is outside the city limits, extending to Evanston on the north and to the various suburbs on the west. This valuation, however, covers only that portion of the system within the city limits. Of the various routes operated, but two enter the loop district, the others serving in most cases as feeder lines to the Chicago Railways Co.

The first table, which covers the physical property on 123,302 miles of track, gives the cost new. Prices are f.o.b. Chicago market prices as of Feb. 1, 1910.

For the purpose of making inventory "Track" was sub-divided into tangent track, track special work, track on bridges, tangent track in car houses and yards, track special work in car houses and yards; and similar sub-divisions were made for the other general divisions, or exhibits.

APPRAISED COST NEW — GENERAL SUMMARY

Track, 124 miles	$2,091,214.13
Electric power distribution	855,966.20
Rolling stock	707,170.80
Power plant equipment	703,084.92
Tools, supplies, furniture, etc.	88,177.91
Buildings	338,626.20
Real estate	84,228.00
Paving	1,014,519.24
	$5,882,987.40
Legal expenses, carrying charges and contingencies, 5%	$ 294,149.37
	$6,177,136.77
Conducting work, furnishing equipment and brokerage, 15%	$ 926,570.52
Total	$7,103,707.29

Tangent track. The track in this section was divided into classes, these classes being determined by the varying weights and types of rails, and by the styles of construction. Under each class an estimate was made of the cost of material and labor required to reproduce the track new at the time of this valuation Nov. 1, 1909, under the original specifications; and to this amount has been added 15% for organization, engineering incidentals, etc., giving the total cost. Data were obtained from detailed examination of the track in the field, in which the length of rail, kind of joint, type of rail and substructure was determined. Additional information was obtained from the track map in the office of the Chicago Consolidated Co. and from representatives of the Consolidated Company. All distances shown are actual field measurements. The lengths of the various pieces of special work were excluded in determining tangent track distances.

Track Special Work. Each piece of special work was measured, listed and sketched. In order to determine the cost new of the special work complete there was added to the cost of the layout the cost of ties, ballast, excavation, labor and miscellaneous items necessary to install same.

Track on Bridges. The cost of track on bridges includes the cost of rail laid together with that of miscellaneous track material used in bridge construction.

Track in Car House and Yards. The track was measured in detail, and unit estimates were made of the cost to construct new.

Track Special Work in Car Houses and Yards. Each house layout was measured and listed and a sketch of the layout was made.

Valuation. The total mileage of track appraised was 123,302 miles. The several classes of track construction found are described in the following schedule and the valuation of each class is given below:

SCHEDULE I.—CLASSES OF TRACK CONSTRUCTION

Class	Description
A	9-in. 129-lb. Lorain rail, 58-ft. lengths, concrete foundation, welded joints, 10 ft. 2 in. centers, type 2-A. Board of Supervising Engineers.
A-1	9-in. 129-lb. Lorain rail, 58-ft. lengths, crushed stone ballast, welded joints, 10 ft. 2 in. centers, type 3. Board of Supervising Engineers.
B	7.1875-in. 85-lb. girder rail, 30-ft. lengths, no ballast, 3 ft. tie spacing, tie plates on every other tie, bonded joints, 9 ft. 6 in. centers, 7.5 ft. tie rod spacing.
B-1	7 3-16-in. 85-lb. girder rail, 30-ft. lengths, no ballast, 3-ft. tie spacing, tie plates on every other tie, 11 ft. 6-in. centers, bond joints, 1½ ft. tie rod spacing.
B-2	7 3-16-in. 85-lb. girder rail, 60-ft. lengths, no ballast, 2½-ft. tie spacing, tie plates on every other tie, bonded joints, 7½-ft. tie rod spacing.
B-3	7 3-16-in., 85-lb. girder rail, 30-ft. lengths, no ballast, 2-ft. tie spacing, tie plates on every other tie, bonded joints, 7½-ft. tie rod spacing.
B-4	7 3-16-in., 85-lb. girder rail, 60-ft. lengths, cinder ballast, 2-ft. tie spacing, no tie plates, welded joints, 7½-ft. tie rod spacing.
C	7-in., 96-lb. Trilby (L 357), 30-ft. lengths, no ballast, 2-ft. tie spacing, tie plates on every other tie, bonded joints, 7½-ft. tie rod spacing.

Class	Description
D	6-in., 78-lb. girder (L-225), 30-ft. lengths, no ballast, 2-ft. tie spacing, tie plates on every other tie, bonded fish-plate joints, 7½-ft. tie rod spacing.
D-1	6-in., 78-lb. girder (L-225), 60-ft. lengths, no ballast, 2-ft. tie spacing, tie plates on every other tie, welded joints, 7½ ft. tie rod spacing.
E	4½-in., approx. 70-lb. girder rail, 30-ft. lengths, no ballast, rail on chairs, 2-ft. tie spacing, 7½-ft. tie rod spacing.
F	8¾-in., 96-lb. girder rail, 30-ft. lengths, cinder ballast, 2½-ft. tie spacing, braced tie plates on every tie, bonded fish-plate joints, 7½-ft. tie rod spacing. Total cost per mile $12,153.62
F-1	8 25-32-in. girder rail, 96 lb., 30-ft. lengths, stone ballast, 2-ft. tie spacing, braced tie plates on every tie, 7½ ft. tie rod spacing, bonded fish-plate joints.
F-2	8 25-32 in., 96-lb. girder (L-206), 60-ft. lengths, cinder ballast, 2-ft. tie spacing, braced tie plate on every tie, 7½-ft. tie rod spacing, welded points.

Class A.— 9-in. 129-lb. Lorain rail, 58-ft. lengths, concrete foundation, welded joints, Type 2A, Board of Supervising Engineers; 6.209 miles.

Estimate of cost to produce one mile of single track. 10-ft. 2-in. centers.

UNIT COST ESTIMATE

9-in. 129-lb. Lorain rail, 202.71 ton at $39.00	$ 7,905.69
Tie rods, 910 ton at $0.25	227.50
Joints, 195 ton at $5.00	975.00
Ties, 6-in. by 8-in. by 8 ft., 1,820 ton at $0.70	1,274.00
Tie plates, 3,640 ton at $0.09	327.60
Screw spikes, 7,280 ton at $0.022	156.52
Lag screws (Fetter drive), 7,280 ton at $0.004	29.12
Cement, 2,034 bbl. at $1.60	3,254.40
Sand, torpedo, 969 cu. yds. at $1.00	969.00
Stone, 1,831 cu. yds. at $1.50	2,746.50
Track labor (see details attached), 5,280 ft. at $0.79	4,171.20
Teaming (see details attached), 5,280 ft. at $0.99	5,227.20
	$27,263.73
Organization, engineering and incidentals, 15%	4,089.56
Total cost per mile	$31,353.29

Class A-1.— 9-in. 129-lb. Lorain rail, 58-ft. lengths, crushed stone ballast, welded joints. Type No. 3, Board of Supervising Engineers; 9.065 miles.

Estimate of cost to produce one mile of single track. 10-ft. 2-in. centers.

UNIT COST ESTIMATE

Rail, 202.71 ton at $39.00	$7,905.69
Tie rods, 910 ton at $0.25	227.50
Joints, 195 at $5.00	975.00
Ties, 2,640 at $0.70	1,848.00
Tie plates, 5,280 at $0.09	475.20
Screw spikes, 10,560 at $0.022	227.04
Lag screws (fetter drive), 10,560 at $0.004	42.24
Cement, 1,263 bbl. at $1.60	2,020.80
Sand, torpedo, 600 cu. yds. at $1.00	600.00
Stone, crushed, 2,162 cu. yds. at $1.50	3,243.00
Track labor (see details attached), 5,280 ft. at $0.79	4,171.20
Track teaming (see details attached), 5,280 ft. at $0.99	5,227.20
	$26,962.87
Organizing, engineering and incidentals, 15%	4,044.43
Total cost per mile	$31,007.30

Class B.— 7 3-16-in. girder rail, 85-lb. 30-ft. lengths, no ballast, 3-ft. tie spacing, tie plates on every other tie, bonded joints; 1.006 miles.

Estimate of cost to produce one mile of single track. 9-ft. 6-in. centers.

UNIT COST ESTIMATE

Rail, 85 lb. per yd. (delivered), 133.57 ton at $40.00....	$5,342.80
Hauling to street, 133.57 ton at $1.00	133.57
Excavation (9 ft. 6-in. centers), 2,410 cu. yds. at $0.50..	1,205.00
Ties delivered, 1,760 at $0.70	1,232.00
Tie rods, 700, at $0.21	147.00
Tie plates (braced), 1,760, at $0.18	316.80
Rail chair joints, complete, 352 at $1.10	387.20
Spikes, 30 kegs at $4.00	120.00
Labor — Track laying, 5,280 ft. at $0.30	1,584.00
	$10,468.37
Organization, engineering and incidentals, 15%..........	1,570.25
Total cost per mile	$12,038.62

Class B-1.— 7 3-16 in. girder rail, 85-lb. 30-ft. lengths, no ballast, 3-ft. tie spacing, tie plates on every other tie, bonded joints; 6.893 miles.

Estimate of cost to produce one mile of single track, 11-ft. 6-in. centers.

UNIT COST ESTIMATE

Rail, 85 lb. per yd. (delivered), 133.57 ton at $40.00....	$5,342.80
Hauling to street, 133.57 ton at $1.00	133.57
Excavation (11-ft. 6-in. centers), 2,610 cu. yds. at $0.50.	1,305.00
Ties delivered, 1,760 at $0.70	1,232.00
Tie rods, 700, at $0.21	147.00
Tie plates (braced), 1,760 at $0.18	316.80
Rail chair joints, complete, 352 at $1.10	387.20
Spikes, 30 kegs at $4.00	120.00
Labor — Track laying, 5,280 ft. at $0.30	1,584.00
	$10,568.37
Organization, engineering and incidentals, 15%..........	1,585.25
Total cost per mile	$12,153.62

Class B-2.— 7-3/16 in. girder rail, 85 lb. 60 ft. lengths, no ballast, 2.5 ft. tie spacing, tie plates on every other tie, bonded fish joints; 16.196 miles.

Estimate of cost to produce one mile of single track.

UNIT COST ESTIMATE

Rail, 85 lb. per yd. (delivered), 133.57 ton at $40.00....	$5,342.80
Hauling rail to street, 133.57 ton at $1.00	133.57
Excavation, 2,410 cu. yds. at $0.50	1,205.00
Ties delivered, 2,112 at $0.70	1,478.40
Tie rods, 700 at $0.21	147.00
Tie plates, 2,112 at $0.18	380.16
Spikes, 35 kegs at $4.00	140.00
Fish plates (complete) 176 at 60 lb. each, 4.72 ton at $42	198.24
Labor, track laying, 5,280 ft. at $0.30	1,584.00
	$10,609.17
Organization, engineering and incidentals, 15%	1,591.38
Total cost per mile	$12,200.55

Class B-3.— 7 3/16 in., girder rail, 85 lb., 30 ft. lengths, no ballast, 2 ft. tie spacing, tie-plates on every other tie, bonded fish-plate joints, 7½-ft. tie-rod spacing: 60,667 miles. Estimate of cost to produce one mile of single track,

UNIT COST ESTIMATE

Rail, 85 lb. per yd. 133.57 ton at $40.00	$5,342.80
Hauling rail to street, 133.57 ton at $1.00	133.57
Excavation, 2,500 cu. yds. at $0.50	1,250.00
Ties delivered, 2,640 at $0.70	1,848.00
Tie rods, 700 at $0.21	147.00
Spikes, 40 keg $4.00	160.00
Fish plates (complete): 352 at 60 lb. each, 9.44 ton at $42	396.48
Labor — track laying, 5,280 ft. at $0.30	1,584.00
	$11,292.05
Organization, engineering and incidentals, 15%	1,693.81
Total cost per mile	$12,985.86

Class B-4.— 7 3/16 in. girder rail, 85 lb. 60 ft. lengths, cinder ballast, 2 ft. tie spacing, no tie-plates, welded joints, 7½ ft. tie-rod spacing; 1.909 miles.

Estimate of cost to produce one mile of single track.

UNIT COST ESTIMATE

Rail, 85 lb. per yd., 133.57 ton at $40.00	$5,342.80
Hauling rail to street, 133.57 ton at $1.00	133.57
Excavation, 2,500 cu. yds. at $0.50	1,250.00
Ties delivered, 2,640 at $0.70	1,848.00
Tie rods, 700 at $0.21	147.00
Spikes, 40 kegs at $4.00	160.00
Ballast, cinder, 1,400 cu. yds. at $0.90	1,260.00
Welded joints (cast), 176 at $4.25	748.00
Labor, track laying, 5,280 ft. at $0.30	1,584.00
Labor, handling ballast, 5,280 ft. at $0.05	264.00
	$12,737.37
Organization, engineering and incidentals, 15%	1,910.61
Total cost per mile	$14,647.98

Class C.— 7-in. 96 lb. Trilby (L-357) 30 ft. lengths. No ballast; 2 ft. tie spacing; tie-plates every other tie; bonded fish-plate joints; tie-rod spacing 7½ ft.; 1.488 miles.

Estimate of cost to produce one mile of single track.

UNIT COST ESTIMATE

Rail, 96 lb. trilby, 150.86 ton at $40.00	$6,034.40
Hauling rail to street, 150.86 ton at $1.00	150.86
Excavation, 2,410 cu. yds. at $0.50	1,205.00
Ties, delivered, 2,640 at $0.70	1,848.00
Tie rods, 700 at $0.21	147.00
Tie plates, 2,640 at $0.18	475.20
Spikes, 40 kegs at $4.00	160.00
Fish plates, complete, 352 at 60 lb. each, 9.44 tons at $42.00	396.48
Labor at 30 ct. per ft., 5,280 ft. at $0.30	1,584.00
	$12,000.94
Organization, engineering and incidentals, 15%	1,800.14
Total cost per mile	$13,801.08

Class D.— 6 in. 78-lb. girder (L-225) 30 ft. length. No ballast; 2 ft. tie spacing; tie-plates every other tie; bonded fish-plate joints; tie-rod spacing 7.5 ft.; 0.529 miles.

Estimate of cost to produce one mile of single track.

UNIT COST ESTIMATE

Rail, 78-lb. girder, 122.57 tons at $40.00	$4,902.80
Hauling to street, 122.57 tons at $1.00	122.57
Excavation, 2,410 cu. yds. at $0.50	1,205.00
Ties, delivered, 2,640 at $0.70	1,848.00
Tie rods, 700 at $0.21	147.00
Tie plates, 2,640 at $0.18	475.20
Spikes, 40 kegs at $4.00	160.00
Fish plates, complete, 352 at 60 lbs., 9.44 tons at $42.00	396.48
Labor, at 30 ct. per ft., 5,280 ft. at $0.30	1,584.00
	$10,841.05
Organization, engineering and incidentals, 15%	1,626.16
Total cost per mile	$12,467.21

Class D-1.— 6-in., 78-lb. girder (L-225), 60-ft. lengths, no ballast, 2-ft. tie spacing, tie plates on every other tie, welded joints, 7.5 ft. tie rod spacing; 3.448 miles.
Estimate of cost to produce one mile of single track.

UNIT COST ESTIMATE

Rail — 78-lb. girder, 122.57 tons at $40.00	$4,902.80
Hauling to street, 122.57 tons at $1.00	122.57
Excavation, 2,410 cu. yds. at $0.50	1,205.00
Ties delivered, 2,640 at $0.70	1,848.00
Tie rods, 700 at $0.21	147.00
Tie plates, 2,640 at $0.18	475.20
Spikes, 40 kegs at $4.00	160.00
Welded joints — cast, 176 at $4.25	748.00
Labor — track laying, 5,280 ft. at $0.30	1,584.00
	$11,192.57
Organization, engineering and incidentals, 15%	1,678.89
Total cost per mile	$12,871.46

Class F.— 8.75-in. girder rail, 96-lb., 30-ft. lengths, cinder ballast, 2-ft. 6-in. tie spacing, braced tie plates on every tie, 7.5 ft. tie rod spacing, bonded fish-plate joints; 7.712 miles.
Estimate of cost to produce one mile of single track.

UNIT COST ESTIMATE

Rail, 8.75-in. 96-lb. girder (L-206), 150.86 tons at $40.00	$6,034.40
Hauling to street, 150.86 tons at $1.00	150.86
Excavation, 2,500 cu. yds. at $0.50	1,250.00
Ties, 2,112 at $0.70	1,478.40
Tie-plates, 4,224 at $0.18	760.32
Tie-rods, 700 at $0.21	147.00
Cinder ballast, 1,400 cu. yds. at $0.90	1,260.00
Fish-plates complete, 352 at 126 lb., 19.8 tons at $42.00	831.60
Spikes, 40 kegs at $4.00	160.00
Labor, track laying, 5,280 ft. at $0.30	1,584.00
	$13,656.58
Organization, engineering and incidentals, 15%	2,048.49
Total cost per mile	$15,705.07

Class F-1.— 8.78125-in. girder rail, 96-lb. 30-ft. lengths, stone ballast, 2 ft. tie spacing, braced tie-plates on every tie; 7.5 ft. tie-rod spacing, bonded fish-plate joints; 0.995 miles.
Estimate of cost to produce one mile of single track.

UNIT COST ESTIMATE

Rail, 8.78125-in. 96-lb. girder (L-206), 150.86 tons at $40.00	$6,034.40
Hauling to street, 150.86 tons at $1.00	150.86
Excavation, 2,500 cu. yds. at $0.50	1,250.00
Ties, 2,640 at $0.70	1,848.00
Tie plates, 5,280 at $0.18	950.44
Tie rods, 700 at $0.21	147.00
Fish plates, complete, 356 at 126 lbs. 19.8 tons at $42.00	831.60
Spikes, 40 kegs at $4.00	160.00
Ballast — stone, 1,400 cu. yds. at $1.50	2,100.00
Labor, track laying and ballasting, 5,280 ft. at $.35	1,848.00
	$15,320.30
Organization, engineering and incidentals 15%	2,298.05
Total cost per mile	$17,618.35

Class F-2.— 8.78125-in. 96-lb. girder (L-206) 60-ft. lengths, cinder ballast, 2-ft. tie spacing, braced tie plates on every tie, 7.5 ft. tie rod spacing, welded joints; 0.936 miles.

Estimate of cost to produce one mile of single track.

UNIT COST ESTIMATE

Rail — 8.78125-in. 96-lb. (L-206), 150.86 tons at $40.00	$6,034.40
Hauling to street, 150.86 tons at $1.00	150.86
Excavation, 2,500 cu. yds. at $0.50	1,250.00
Ties delivered, 2,640 at $0.70	1,848.00
Tie plates, 5,280 at $0.18	950.40
Tie rods, 700 at $0.21	147.00
Spikes, 40 kegs at $4.00	160.00
Ballast, cinder, 1,400 cu. yds. at $0.90	1,260.00
Welded joints, cast, 176 at $4.25	748.00
Labor, track laying, 5,280 ft. at $0.30	1,584.00
Labor, handling ballast, 5,280 ft. at $0.05	264.00
	$14,396.66
Organization, engineering, incidentals, etc., 15%	2,159.50
Total	$16,556.16

CROSS-OVERS (BUILT UP)

Cross-over delivered, 1 at $600	$600.00
Excavation (70 ft. by 9 ft. by 1.25 ft.) 30 cu. yds. at $0.50	15.00
Ballast, 25 cu. yds. at $1.65	41.25
Ties, 1,700 b. m. at $30	51.00
Spikes, 1 keg at $4.00	4.00
Labor, 400 hrs. at $0.18	72.00
Total	$783.25

CROSS-OVERS: 9 IN. MANGANESE — 10 FT. 2 IN. CENTERS. BOARD OF SUPERVISING ENGINEERS' TYPE

Cross-over complete, 1 at $1,100	$1,100.00
Ballast, 17 cu. yds. at $1.50	25.50
Ties (7 in. by 9 in. oak switch ties), 1,700 b. m. at $30	51.00
Spikes, 1 keg at $4.00	4.00
Tie plates, 70 at $0.09	6.30
Stone for concrete, 14 cu. yds. at $1.50	21.00
Sand, Torpedo, 7 cu. yds. at $1	7.00
Cement, 15 bbls. at $1.65	24.75
Total material	$1,239.55

Labor, 600 hrs. at $0.18	$ 108.00
Teaming, 20 hrs. at $0.55	11.00
Total cost	$1,358.55

Excavation included in labor and teaming.

DOUBLE TRACK CROSSING: ELECTRIC OVER STEAM

Layout, delivered, $200 a crossing, 4 at $200	$800.00
Excavation, 20 cu. yds. at $0.50	10.00
Ballast, 17 cu. yds. at $1.50	25.50
Ties, delivered, 30 at $0.70	21.00
Spikes, 1 keg at $4.00	4.00
Wire nails, 40 lbs. at $0.03	1.20
Hemlock plank, 960 b. m. at $25	24.00
Labor,	100.00
Total	$985.70

SINGLE TRACK BRANCH OFF; 45 TO 90 DEGREES

Layout:	
1 switch and mate	$125.00
1 frog	45.00
Tangent rail included, 50 ft. at $0.75	37.50
Curved track included, 75 ft. at $3.00	225.00
Joints, 16 pair complete at $1.10	17.60
Tie plates, 150 at $0.09	13.50
	$463.60
Excavation, 43 cu. yds. at $0.50	21.50
Ballast, 40 cu. yds. at $1.50	60.00
Ties, 1,200 b. m. at $30.00	36.00
Spikes, 1 keg at $4.00	4.00
Labor	100.00
Total material and labor	$685.10

DOUBLE TRACK BRANCH OFF; 45 to 90 DEGREES

Layout complete (tie plates and joints included), 1 at $1,000	$1,000.00
Excavation, 80 cu. yds. at $0.50	40.00
Ballast 72 cu. yds. at $1.50	108.00
Ties, 2,500 b. m. at $30	75.00
Spikes, 2 kegs at $4	8.00
Labor	200.00
Total material and labor	$1,431.00

DOUBLE TRACK OVER SINGLE TRACK CROSSING. SINGLE CONNECTING CURVE

Layout complete (tie plates and joints included) 1 at $1,044.16	$1,044.16
Excavation, 78 cu. yds. at $0.50	39.00
Ballast, 64 cu. yds. at $1.50	96.00
Ties, 2,200 b. m. at $30	66.00
Spikes, 2 kegs at $4	8.00
Labor	200.00
Total material and labor	$1,453.16

DOUBLE TRACK CROSSING. ONE CONNECTING CURVE. 45 DEGREES

Layout complete (tie-plates and joints included) 1 at $1,397.00	$1,397.00
Excavation, 90 cu. yds. at $0.50	45.00
Ballast, 74 cu. yds. at $1.50	111.00
Ties, 2,660 b. m. at $30	79.80
Spikes, 2 kegs at $4	8.00
Labor	250.00
Total material and labor	$1,890.80

DOUBLE TRACK CROSSING. SINGLE TRACK CURVES IN TWO QUADRANTS

Layout complete delivered (tie plates and joints included), 1 at $2,088.32	$2,088.32
Excavation, 156 cu. yds. at $0.50	78.00
Ballast, 129 cu. yds. at $1.50	193.50
Ties, 4,460 b. m. at $30	133.80
Spikes, 4 kegs at $4	16.00
Labor	350.00
Total material and labor	$2,859.62

DOUBLE TRACK CROSSING WITH DOUBLE TRACK CONNECTING CURVES

Price of double track crossing with single connecting curve	$1,890.80
Additional:	
Switch and mate, 2 at $125	250.00
Jump frogs, 10 at	.....
50 ft. curved track at $4.45	222.50
Total cost of crossing	$2,363.30

DOUBLE TRACK — THREE PART WYE

Curved track	376.4
Straight track included	206.6
Total length	583.0 ft.
Rail layout delivered	$2,500.00
Excavation, 210 cu. yds. at $0.50	105.00
Ballast, 200 cu. yds. at $1.50	300.00
Ties, 2,500 b. m. at $30	75.00
Spikes, 5 kegs at $4	20.00
Labor 583 ft. at $0.75	437.25
Total cost	$3,437.25

SINGLE TRACK RAILWAY CROSSING. DOUBLE TRACK ELECTRIC OVER SINGLE TRACK STEAM. 45 TO 90 DEGREES

Layout delivered (tie plates and joints included), 2 at $200	$400.00
Excavation, 11.5 cu. yds. at $0.50	5.75
Ballast, 10 cu. yds. at $1.50	15.00
Ties, delivered, 16 at $0.70	11.20
Spikes, .5 keg at $4	2.00
Hemlock planking — 12 pieces, 3 ins. by 10 ins. by 16 ft., 480 b. m. at $25	12.00

Nails	$ .60
Labor	65.00
Total cost	$511.55
For cost of jump crossing, deduct	$261.00
Net cost of jump crossing	$250.55

DOUBLE TRACK CROSSING. ELECTRIC OVER STEAM

Layout, delivered, $200 a crossing, 4 at $200	$800.00
Excavation, 20 cu. yds. at $0.50	10.00
Ballast, 17 cu. yds at. $1.50	25.50
Ties, delivered, 30 at $0.70	21.00
Spikes, 1 keg at $4.00	4.00
Wire nails, 40 lbs. at $0.03	1.20
Hemlock plank, 960 b. m. at $25	24.00
Labor	100.00
Total	$985.70

PLAIN CURVES. PER FT. OF SINGLE TRACK. 7-IN. RAIL

Rail — delivery and shop bending included	$3.00
Excavation	0.25
Ballast	0.41
Ties delivered	0.30
Tie plates	0.06
Tie rods	0.03
Fish-plates and bolts	0.08
Spikes	0.02
Labor laying track	0.30
	$4.45

Estimated Cost of One Mile of Single Track. The following data are abstracted from "Detailed Exhibits of the Physical Property and Intangible Values of the Calumet Electric Street Railway Company and the South Chicago City Railway Company as of February 1, 1908, accompanying the valuation report submitted to the committee on local transportation of the Chicago City Council, by B. J. Arnold and George Weston." An estimate was made of the cost of materials and labor required to reproduce the property new, to which was added 15% for organization, engineering and incidentals.

ESTIMATE OF COST OF 1 MILE OF SINGLE TRACK

6-IN. GIRDER RAIL, 75-LB., 30-FT. LENGTHS, BONDED, ON STONE BALLAST

117.86 tons rail, delivered, at $41.00	$4,832.26
117.86 tons rail, hauling to street, at $1.00	117.86
2,640 cu. yds. excavation, at $0.50	1,320.00
1,500 cu. yds. slag ballast, at $1.65	2,475.00
2,640 ties, delivered, at $0.75	1,980.00
1,056 tie rods, at $0.30	316.80
2,640 tie plates, at $0.22	580.80
9.44 tons fish plates and bolts, 60 lbs. each, at $42.25	398.84
30 kegs spikes for rails, at $4.10	123.00
10 kegs spikes for tie plates, at $4.10	41.00
18 cross bonds, at $2.00	36.00

352 bonds at $1.25 ($0.80, material; $0.45, labor)	$ 440.00
5,280 ft. track laying, at $0.35	1,848.00
	$14,509.56
15%, organization, engineering, incidentals	2,176.43
	$16,685.99

If Atlas joints are used the estimate of cost is $17,461.97 per mile of single track, the difference being due to the increased cost of Atlas joints over fish plates, $113.72 per ton as against $42.25 per ton.

If the track is on cinder ballast with no excavation the estimated cost per mile is $13,874.23 where fish plates are used and $14,650.21 for track with Atlas joints. Cinder ballast is taken as 1,500 cu. yd. at $0.90.

For welded joints on stone ballast the estimated cost is $17,441.72 per mile of single track. There would be 352 welded joints at $4.25 each, but fish plates and bonds are not required.

6-IN. GIRDER RAIL, 78-LB., 30-FT. LENGTHS, SPLICE PLATES, BONDED ON SLAG OR STONE BALLAST

122.57 tons rail, delivered, at $41.00	$5,025.37
122.57 tons rail, hauling to street, at $1.00	122.57
All other items same as 75-lb. rail, total	9,559.44
	$14,707.38
15%, organization, engineering, incidentals	2,206.12
	$16,913.50

In similar manner the following costs per mile of single track are figured: $17,149.06 for 7-in. girder, 80 lb., 30 ft. lengths, bonded, on stone ballast; $17,046.40 for 7³⁄₁₆-in. girder, 85 lb., 60-ft. lengths, bonded, on stone ballast; $23,687.66 for this last if it has a reinforced concrete base instead of a stone base; the price of concrete being taken, 1500 cu. yd. at $5.50.

45-LB. T RAIL, SLAG BALLAST, BONDED JOINTS

70.71 tons rail, delivered, at $31.00	$2,192.00
70.71 tons rail, hauling to street, at $1.00	70.71
1760 cu. yds. slag ballast, at $1.65	2,904.00
2,640 ties, delivered, at $0.75	1,980.00
4 tons splice bars, bolts, nut locks, at $46.50	186.00
30 kegs spikes for rails, at $4.10	123.00
18 cross bonds, at $2.00	36.00
352 bonds, at $1.25	440.00
5,280 ft. track laying, at $0.30	1,584.00
	$9,515.71
15% organization, engineering, incidentals	1,427.35
	$10,943.06

In like manner the estimate of cost to produce one mile of single track is $11,846.54 for 60-lb. trail, slag ballast, bonded joints and $13,117.93 for 80-lb. trail, slag ballast, bonded joints.

Straight Track in Car Houses and Yards. The following are the estimated costs of one foot of track of various kinds and weights,

used by B. J. Arnold and George Weston in their valuation of the South Chicago City Railway.

Strap Rail. Steel, \$0.02 per lb. delivered; screws, \$0.41 per gross; labor, \$0.08 per ft.

T-Rail, 2¾-in., \$0.02 per lb., delivered; 56, 60 and 75 lb., \$31.00 per long ton; splice bars, \$41.00 per long ton; spikes, for 2¾-in. rail, \$4.10 per keg of 600; for other rail, \$4.10 per keg of 375; bolts and nuts, \$0.05 per lb.; ties, hemlock, \$0.50 each, 2 ft. centers; bonding, \$0.75 per joint; excavation, \$0.10 per ft. of track; labor, \$0.10 per ft. of track.

Girder Rail. Steel and fittings, \$41.00 per long ton; bonding, \$0.75 per joint; ties, hemlock, \$0.50 each; spikes, \$4.10 per keg.

TABLE III. ESTIMATED COST OF ONE FOOT OF TRACK

	Strap rail	T rail	T rail	T rail	T rail	Girder rail
Height of rail, ins.	3.875	5	4.25	4.625	2.75	7
Wt. per yd., lbs.	27	75	60	56	25	85
Wt. of 2 splice plates per ft. of track, lbs.	..	2.26	2.13	2.00	0.48	0.60
Wt. of nuts and bolts per ft. of track, lbs.	..	0.82	0.82	0.82	0.524	
Cost, per ft. of track:						
Rails	\$0.37	\$0.69	\$0.59	\$0.52	\$0.34	\$1.04
2 splice plates	..	.04	0.03	0.03	0.01	0.07
Nuts and bolts	..	0.01	0.01	0.01	0.01	
Bonding	..	0.05	0.05	0.05	0.05	0.05
Spikes	..	0.02	0.02	0.02	0.01	0.02
Ties	..	0.25	0.25	0.25	0.25	0.25
Excavation	..	0.10	0.10	0.10	0.10	0.10
Labor	0.08	0.15	0.15	0.15	0.15	0.15
Incidentals	..	0.10	0.10	0.10	0.10	0.10
Total	\$0.45	\$1.42	\$1.30	\$1.23	\$1.02	\$1.78

Track Special Work. These costs are from the Detailed Exhibits of the Physical Property and Intangible Values of the Calumet Electric Street Railway Co., and the South Chicago City Railway Co., as of February 1, 1908, accompanying the Valuation Report submitted to the Committee on Local Transportation of the Chicago City Council by B. J. Arnold and George Weston. Each piece of special work was measured and the determination of its cost new was made by adding to the estimated cost of the material required for the special work, the cost of the ties, joints, ballast, excavation and labor required to install the various types of special work.

ESTIMATE OF COST TO PRODUCE TRACK SPECIAL WORK

SINGLE TRACK CROSSING. ELECTRIC OVER ELECTRIC. 90 DEGREES

1 single crossing complete, with joints	\$170.00
10 ties, 6 ins. by 8 ins. by 8 ft., delivered, at \$0.75	7.50
10 tie plates, at \$0.22	2.20
.25 keg spikes, at \$4.10	1.03
5.9 cu. yds. excavation (10 by 10 by 1.6 ft.) at \$0.50	2.95
2.7 cu. yd. crushed rock (10 by 10 by 1.0 ft., minus tie space) at \$1.65	4.45

8 joints, bonded, at $1.25	$ 10.00
Labor, 20 ft. at $1.25	25.00
	$223.13
15% organization, engineering, incidentals	33.47
	$256.60

For hard center work or for a crossing at 45 degs. add $50.00 to the $223.13.

Estimated weight, 3,000 lbs.

SINGLE TRACK CROSSING SINGLE TRACK. ELECTRIC OVER STEAM. 90 DEGREES

Crossing complete with joints	$300.00
11 ties, at $0.75	8.25
0.15 keg spikes, at $4.10	0.61
6 joints, bonding, at $1.25	7.50
2 cross bonds, at $2.00	4.00
6.8 cu. yds. crush rock (12 by 12 by 1.5 ft. minus space occupied by 6 in. by 8 in. by 8 ft. ties), at $1.65	11.27
12 pieces oak plank, 2 ins. by 12 ins. by 16 ft. = 384 ft.	
12 pieces oak plant, 3 ins. by 12 ins. by 16 ft. = 576 ft.	
960 f. b. m. at $30.00 per M	28.80
Wire nails	1.25
Labor	50.00
	$411.68
Add for crossing at 45 degs.	50.00
	$461.68

Estimated weight 5,500 lbs.

Adding 15% to the above costs for organization, engineering and incidentals gives $473.43 for the 90 deg. crossing and $530.93 for the 45 degs.

SINGLE TRACK CROSSING SINGLE TRACK. ELECTRIC OVER STEAM. BOTH 80-LB. T-RAIL SECTIONS. 90 DEGREES

One track guarded and reinforced; one track guarded only.

Layout complete (Ajax Forge Co.'s quotation)	$210.00
12 ties, at $0.75	9.00
All other material, and labor, same as above	103.68
	$322.68
Add for crossing, 45 degs.	50.00
	$372.68

Estimated weight, 6,500 lbs.

Adding 15% as above the costs would be $371.08 and $428.58 for the 90 deg. and 45 deg. crossings respectively.

SINGLE TRACK BRANCH-OFF CURVES

1 curve, 90 ft. long	90 ft.
Straight track included	24 ft.
Total	114 ft.

Special work, including fish plates	$530.00
57 ties, at $0.75	42.75
57 tie plates, at $0.22	12.54
1 keg spikes, at $4.10	4.10
38.5 cu. yd. crushed rock (114 by 10 by 1 ft. minus space occupied by ties, 6 ins. by 8 ins. by 8 ft.) at $.165	63.52
67.6 cu. yds. excavation (114 by 10 by 1.6 ft.), at $0.50	33.78

12 joints, bonded, at $1.25	$ 15.00
Labor, 114 ft., at $1.25	142.50
	$844.19
Add for hard center work	130.00
	$974.19

Adding 15% the above costs are $970.82 and $1,120.32 respectively.

DOUBLE TRACK CROSSING. 90 DEGREES

Special layout, including fish plates	$700.00
40 ties, at $0.75	30.00
40 tie plates, at $0.22	8.80
1 keg spikes, at $4.10	4.10
24 joints, bonded, at $1.25	30.00
23.7 cu. yds. excavation 20 by 20 by 1.6 ft.), at $0.50	11.85
10.9 cu. yds. crushed rock (20 by 20 by 1 ft., minus space occupied by 40 ties, 2.6 cu. ft. per tie), at $1.65	17.98
Labor, 80 ft. at $1.25	100.00
	$902.73

Add to this cost $180.00 for hard center work, and $100.00 for a 45 deg. crossing.

Estimated weight, 12,000 lbs.

With 15% added for organization, engineering and incidentals the costs are $1,038.14 for a 90 deg. crossing; $1,245.14 for same with hard center work; $1,153.14 for a 45 deg. crossing.

DOUBLE TRACK CROSSING. CURVES IN ONE QUADRANT. 90 DEGREES

Single track, 260 ft.; curves, 2 each at 90 ft., 180 ft.; total 440 ft.

Special layout, including fish plates	$2,740.00
220 ties, at $0.75	165.00
220 tie plates, at $0.22	48.40
4 kegs spikes, at $4.10	16.40
43 joints, bonded, at $1.25	53.75
234.5 cu. yds. excavation (440 ft. × 0.533 cu. yd. per running ft.), at $0.50	117.25
125.4 cu. yds. crushed rock (440 × 0.285), at $1.65	206.91
Labor, 440 ft., at $1.25	550.00
	$3,897.71
Add for 45 deg. angle	100.00
	$3,997.71

Estimated weight, 50,000 lb.

Adding 15% as before the cost is $4,482.37 for a 90 deg. and $4,597.37 for a 45 deg. crossing.

DOUBLE TRACK CROSSING. CONNECTING CURVES IN TWO QUADRANTS

Such a crossing requires 350 ft. of straight track and 360 ft. of curved track. The special work is estimated at $4,700.00 and figuring the other materials and labor as before the total is $6,667.27, and with 15% added, $7.667.36. Add to the former $1,670.00 for hard center work.

Estimated weight, 85,000 lbs.

DOUBLE TRACK THREE — PART "Y"

Curved track, 360 ft.; straight track included, 170 ft.; total, 530 ft.

Special layout complete, including joints	$2,780.00
265 ties, at $0.75	198.75
265 tie plates, at $0.22	58.30
5 kegs spikes, at $4.10	20.50
282.5 cu. yds. excavation (530 × 0.533), at $0.50	141.25

151 cu. yds. crushed rock (530 × 0.285), at $1.65	$ 249.15
100 joints, bonded, at $1.25	125.00
Labor, 530 ft., at $1.25	662.00
	$4,235.45
Add for hard center work	1,020.00
	$5,255.45

Estimated weight, 50,000 lbs.
Adding 15% these costs are $4,870.77 and $6,043.77.

DOUBLE TRACK BRANCH-OFF

2 curves at 90 ft., 180 ft.; straight track included, 65 ft.; total, 245 ft.

Layout, complete, with fish plates	$1,220.00
123 ties, at $0.75	92.25
123 tie plates, at $0.22	27.06
2 kegs spikes, at $4.10	8.20
36 joints, bonded, at $1.25	45.00
130.6 cu. yds. excavation (245 × 0.533) at $0.50	65.30
69.8 cu. yds. crushed rock (245 × 0.285), at $1.65	115.17
Labor, 245 ft. at $1.25	306.25
	$1,879.23
Add for hard center work	405.00
	$2,284.23

Estimated weight, 23,000 lbs.
Adding 15% these costs are $2,161.11 and $2,626.86.

CROSS-OVER

Cross-over, over all, 57 ft., straight track included, 50 ft.; total, 107 ft.

Cross-over, complete	$600.00
54 ties, at $0.75	40.50
1 keg spikes, at $4.10	4.10
20 joints, bonded, at $1.25	25.00
6 cross bonds, at 1.00	6.00
57 cu. yds. excavation (107 × 0.533), at $0.50	28.50
30.5 cu. yds. crushed rock (107 × 0.285), at $1.65	50.32
Labor, 107 ft. at $1.25	133.75
	$888.17
Add for hard center work	375.00
	$1,263.17

Estimated weight, 11,000 lbs.
Adding 15% these costs are $1,021.40 and $1,452.65.

SINGLE TRACK TURN-OUT

Turn-out, over all, 82 ft.; straight track, 25 ft.; total, 107 ft.

Point and mate	$113.00
Curve cross	45.00
60 ft. curved track, at $4.90	294.00
33 ft. straight track	82.00
Turn-out, complete, special work (estimated wt. 8,500 lbs.)	536.00
54 ties, at $0.75	40.50
1 keg spikes, at $4.10	4.10
15 joints, bonded, at $1.25	18.75
3 cross bonds, at $1.00	3.00
57 cu. yds. excavation (107 × 0.533), at $0.50	28.50

30.5 cu. yd. crushed rock (107 × 0.285), at $1.65	$ 50.32
Labor, 107 ft., at $1.25	133.75
	$814.92
Add for hard center work	250.00
	$1,064.92

Adding 15% these costs are $937.16 and $1,224.66.

PLAIN CURVE TRACK

Cost of curve per ft. of track	$3.00
Cost per ft. of substructure and labor	1.90
	$4.90

Estimated weight, 72 lbs. per ft. of track.

CURVED T-RAIL TRACK

4.25 in. T-rail, 60-lb., per ft.		$2.25
Extra for curving, per ft.		0.25
		$2.50
2 strap guards, 0.625 by 4 ins., at 8.5 lbs. per ft.	17 lbs.	
0.5 of separator per ft., at 4 lb. each	2 lbs.	
19 lbs. at 5 cts. per ft., extra		0.95
		$3.45

Estimated weight, 65 lbs. per ft.

5 in. T-rail, 80-lb., per ft.	$2.50
Extra for curving	0.25
Extra for strap guards	0.95
	$3.70

Estimated weight, 79 lbs. per ft. of track.

Value of 665 Miles of Chicago Street Railways. The value of the properties of the street railways of Chicago, which are under the supervision of Boards of Supervising Engineers, is summarized in the statistical report of the Board for the year ending Jan. 31, 1910.

Original valuation	$55,775,000
Additions to Jan. 31, 1910	42,754,978
Total	$98,529,978

The items making up this summary are given in the following table showing the value per mile of track.

Organization	$5,760
Engineering and superintendence	6,272
Track (exclusive of paving)	35,317
Paving	7,440
Electric line constructing	11,656
Real estate (used in operation)	6,332
Buildings and fixtures	12,898
Investment real estate	1,629
Power plant equipment	7,360
Shop tools and machinery	1,177
Cars, revenue	17,323
Electric equipment of cars	9,165
Miscellaneous equipment	876
Interest and discount	2,553
Miscellaneous	16,993
Tunnels	2,013

Horses	$ 87
Materials and supplies	3,246
Fill	152
Subways	7
Renewals	80
Total per mile of track	$148,336

Appraised Values of the Street Railways of Detroit, Mich. Engineering and Contracting, July 6–13, 1910.

The Detroit United Railway controls all the street railways in the city of Detroit. The franchises on many miles of its track will soon expire. This fact led the mayor, Mr. Philip Breitmeyer, to appoint a committee of 50 citizens to make an investigation and report on the street railway question, one of the duties of the committee being to appraise the value of the physical property of the railways. Frederick T. Barcroft was appointed director of appraisal. His report of the results of the appraisal was dated Oct. 1, 1909.

The first street railway franchise was granted to the Detroit City Ry. Co. in 1862. Since that time 50 corporations have received franchises, but their stock was eventually absorbed by the Detroit United Rys. Co.

The appraisal, which includes 170.4 mi. of main track and 1,000 revenue cars, gives not only the cost of reproduction new, but the depreciated, or second-hand value of the property. We shall first give a summary, followed by costs in great detail. The cost of reproduction new was as follows:

Cost of Reproduction, New.

Real estate	$ 513,548
Buildings, except power houses and battery stations	654,884
Power plants, including buildings	1,481,328
Battery stations, including buildings	228,252
Power distribution, including overhead feed wires and telephone system	1,211,897
Track	3,601,336
Rolling stock, including equipments	3,676,098
Shops	390,968
Tools, materials, supplies, furniture, etc.	751,016
Overhead charges	1,268,000
Total	$13,777,327

The last item was not given in the report, and we have estimated it as explained below.

The depreciated or present value was as follows:

Depreciated Value

Real estate	$ 513,548
Buildings	578,763
Power plants	1,219,051
Battery stations	200,488
Power distribution	1,088,063
Track	2,599,222
Rolling stock	2,861,403
Shops	308,719
Tools, supplies, etc.	728,158
Overhead charges	1,024,310
Total	$11,121,725

Attention should be called to the fact that the item, Track, includes grading, as well as rails, ties, etc., and it includes broken stone, gravel and concrete foundations, but does not include wearing coat of the pavement.

The report says:

"Paving has not been considered an asset of the company in the preparation of this appraisal. * * * Distributing and replacing the pavement adds no value to it. Neither can the company obtain credits, as it requested, for theoretical items. If there is any value to the pavement to which the company is entitled, it must be upon some different theory than that it is an asset, for so far as the company is concerned it is an obligation foreign to its needs as a transportation proposition, and is in lieu of other taxes. When certain taxes and municipal charges are remitted by the authorities, and the company assumes the obligation of paving, there can be no question that the paving thereby becomes a tax.

"The paving can have a value to the company when it was all new and laid at one time, and then only in the sense that they have prepaid their taxes up to the point of the first renewal. Thereafter the repairs and renewal become an annual maintenance charge or tax.

"If the company has charged the maintenance of this paving to capital account, it is not justified in so doing, and has done so because it has not provided for the renewal of any physical property by a depreciation reserve, and if it has charged this to operation or maintenance under those circumstances, the result is a tax, by whatever name it has labeled it.

"The company should have been compelled to charge the cost of original paving to 'cost of initial paving account,' which would be automatically wiped out in eight years, assuming, for example, that this is the life of the paving, by being credited with one-eighth of the cost of the paving annually. The maintenance and repairs after the above date should be charged to operating account 'paving.'"

While there can be no doubt that pavement maintenance should never be charged to capital account, we can not subscribe to the proposition that a street railway company should not charge the entire first cost of a pavement to capital account, unless it is clearly established that city taxes have been remitted to the full extent of the money expended for pavement construction. Nor can we subscribe to the statement that "Disturbing and replacing the pavement adds no value to it," when this viewpoint is used as a reason for not charging paving work to the construction account. The same line of reasoning would lead to rejecting also the item of grading, for "disturbing and replacing" the earth can add no value to the earth, yet it is a necessary part of the labor of construction. However just may have been the reason for excluding an allowance for paving work from the appraised values, it could be proven just only on the ground that the city of Detroit had itself paid for the pavement by remitting taxes equal to its first cost. We should explain that Mr. Barcroft's omission to include the cost

of paving rested upon the opinion of the City Corporation Counsel and a majority of the legal committee to the effect that "the legal title to the pavement is in the city of Detroit and not in the company." This reason is fallacious, for "legal title" does not determine costs nor values in the case of a public service corporation. "Legal title" to the earth beneath the pavement also rests in the city of Detroit. Shall the cost of grading be excluded from the appraisal for that reason? Clearly not, and it is equally clear, therefore, that the cost of paving should be viewed in the same light.

Aside from this one point, the appraised values appear to have been very liberal, taken as a whole, as will be better appreciated from a study of the cost of reproduction new per mile of trackway, given below.

Regarding overhead charges, the report says:

"Overhead charges should be depreciated in the same proportion as the present condition of the physical property bears to its cost, and this charge, when added to the physical elements depreciated, represents the net depreciated physical and overhead value of the property. * * * The sum total of this analysis, therefore, leads to the conclusion that $1,024,310 is ample to cover such overhead charges as are necessary to reproduce this property."

Deducting this $1,024,310 from the total present value leaves $10,097,415, which is 80.74% of the cost of reproduction new of the total physical property. Hence we have divided the $1,024,310 by 80.74% to obtain the undepreciated overhead charges, which are $1,268,000 as thus found. If the real estate is not included, the ratio is 79.89%, instead of 80.74%, and we get $1,282,000 as the undepreciated overhead charges.

Apparently the undepreciated overhead charges were estimated at a little more than 10% of the cost of the property. The overhead charges include: Organization, finance, interest and taxes during construction, legal expense, insurance, contingencies, technical assistance employed in the various engineering branches, and other miscellaneous expenses.

The track mileage was as follows:

	Miles
Single track	170.41
Car stations, yards, etc.	12.93
Total	183.34

Dividing each of the ten items of cost of reproduction new by the 170.41 miles of trackway, we have the following cost per mile of trackway:

Cost of Reproduction, New.

		Per mile
1.	Real estate	$ 3,013
2.	Buildings (other than power)	3,843
3.	Power plants (including buildings)	8,694
4.	Battery stations (including buildings)	1,339
5.	Power distribution	7,112
6.	Track (including grading, but excluding paving)	21,135

		Per mile
7.	Rolling stock (6 cars per mile)	$21,572
8.	Shops	2,294
9.	Tools, supplies, etc.	4,407
10.	Overhead charges	7,441
	Total	$80,850

Since there are 1.076 miles of all track to each mile of trackway, each of these 10 items must be divided by 1.076 to get the cost per mile of track.

The annual number of car miles per mile of track is evidently large, for there are 6 revenue cars per mile of trackway. This accounts for the high cost of power plants per mile of trackway. Items 8 and 9 are inordinately high, but the shops and tools are used not only for the street railways within the city but for interurban lines.

We pass now to the detailed estimates of cost of reproduction new and present value.

1. *Real Estate.*— There are 50.021 acres used for railway purposes, valued at $513,548, or an average of $10,265 per acre. In addition there are 18.374 acres valued at $121,772, but not used for railway purposes. The following is a summary of the real estate, not including buildings:

	Land for:	
1.	General offices	$ 27,750
2.	Power houses	185,169
3.	Emergency station	9,375
4.	Mechanical shops	50,000
5.	Track shops	24,832
6.	Battery stations (two)	18,514
7.	Car stations (ten)	186,664
8.	Air changing stations (two)	2,600
8a.	Car clearances (two)	1,944
8b.	Switching yards (two)	6,200
8c.	Loop property	500
9.	Freight depot (interurban traffic)	50,000
	Total	$563,548

2. *Buildings.*— The following is the estimated cost of reproduction new:

1. General office, 5-story brick, trimmed with cut stone, pile foundation, 37 by 100 ft.	$ 42,000
2. Power houses (see Power Plants):	
Pipe house, 1-story brick, 44 by 142	7,500
Stable, 1-story brick, 52 by 111	3,500
Two frame buildings	600
Miscellaneous: Sheds, paving, walks, etc.	10,000
3. Emergency station, 2 and 3 stories, 75 by 200	42,459
4. Car repair shops:	
2-story brick, 72 by 463 ft.	44,000
1 to 3-story brick, 85 by 538 ft.	89,000
Sprinkler system in buildings	21,000
Scrap yard buildings	2,600
5. Machine shops, 1-story frame, 79 by 145 ft.	8,500
Stock room	2,500
Carpenter shop	6,000
Cement shed	3,000

Stone crusher building	$ 3,300
Miscellaneous	500
6. Battery stations (see Battery Stations).	
7. Car stations:	
1 and 2-story brick, 41 by 166 ft.	10,900
1-story brick, 94 by 215 ft.	14,000
1-story frame office, 30 by 39 ft.	2,000
1-story brick, 158 by 353 ft.	38,000
1½-story brick (65 by 254) and 1-story office and barn (69 by 254)	30,000
2-story brick, 43 by 151 and 43 by 35 ft.	13,500
Brick storage shed, 80 by 750	40,500
Coal and tool sheds	800
1-story brick, 94 by 228 ft.	15,500
Office and air charging station	2,800
1-story brick, 100 by 243 ft.	17,000
1 and 2-story brick, 80 by 389 ft.	36,000
1-story brick, 64 by 470 ft.	20,000
Frame office, 41 by 52 ft.	2,600
1-story brick, 73 by 366 ft.	30,500
2-story frame office, 28 by 46	2,500
Shed, 16 by 68 ft.	725
Brick, steel trussed roof, 82 by 141 ft.	23,500
2-story brick, wood trussed roof, 58 by 150 ft.	12,300
1-story frame office	1,650
1-story brick, steel trussed roof, 73 by 158	13,600
8. Air charging stations:	
Frame, 10 by 40 ft.	200
Frame, 32 by 70 ft.	2,600
Total	$617,884
9. Freight depot:	
Masonry building, 43 by 200 ft.	13,500
Masonry building, 38 by 250 ft.	12,600
Milk depot	3,200
Platform, ret wall, paving and grading	7,700
Grand total	$654,881

Item 9, freight depot, is owned by the Electric Depot Co., and is used in handling interurban freight. These buildings having a cost of reproduction new of $654,884, are given a present value of $578,-763.

In addition there were buildings not used for railway purposes to which were assigned a cost of reproduction of $64,084 and a present value of $20,045.

Item 4, car repair shops, is not pro rated to city use only, but includes all the shops. Since these shops are also used for cars on suburban and interurban lines, it is probable that their cost is somewhat greater than necessary for the urban traffic only.

Buildings for housing power plants are not given under this heading but under Power Plants.

3. *Power Plants.*— There are two power plant stations built in 1894–5. The power buildings are of brick and stone with concrete bases. The combined capacity of the two stations is 13,500 kw., but the railway company secures 3,500 kw. additional by purchase from the Edison Co.

The cost of reproduction new of Station A, which has 5,500 kw. capacity, is as follows:

1. Machinery, foundations, stone, brick and concrete	$ 26,250
2. Boilers and settings:	
12 Babcock & Wilcox, 250 hp. each, 4 Sterling boilers, 354 h.p. each. Total	44,384
3. Coal and handling apparatus	6,917
4. Coal storage bins and chutes	6,588
5. Grates and stokers:	
16 Murphy furnaces and stokers	13,176
6. Breeching connections	2,965
7. Stack:	
Self-supporting steel, fire brick lined to top, 11½ ft. diam. of flue, 183 ft. high above brick foundation, 205 ft. above ground level, rests on 168 piles..	11,550
8. Feed water heaters:	
1 Cochran open heater (2,000 h.p.)	
1 Worthington duplex.	
Total	1,500
9. Purifiers: 6 Hoppe, 750 h.p. each	3,150
10. Intake tunnels	19,050
11. Condensing equipment:	
4 Worthington duplex air pumps and condensers.	
1 Tomlinson barometric condenser.	
1 Lawrence centrifugal (10-in.) pump and engine.	
Total	16,500
12. Circulating and boiler feed pumps:	
3 Worthington feed pumps.	
Total	3,294
13. Piping, valves and covering	44,000
14. Engines:	
4 Allis-Chalmers, 1,500 h.p. each, tandem compound, condensing.	
1 Allis-Chalmers, 2,500 h.p. cross-compound, condensing.	
Total	129,977
15. Generators:	
2 General Electric, 1,000 kw. each.	
2 Westinghouse, 1,000 kw. each.	
1 Westinghouse, 1,500 kw. each.	
Total	87,000
16. Boosters:	
1 Westinghouse generator, 250 kw.	
1 Westinghouse generator, 350 kw.	
1 Westinghouse motor, 272 kw.	
1 Cutler-Hammer, 272 kw.	
1 Westinghouse motor, 388 kw.	
1 Westinghouse starting box, 388 kw.	
Total	10,617
17. Crane, Brown Hoisting Co., hand operated, 60-ft. span, 25-ton cap	4,400
18. Generator and switchboard cables	9,900
19. Switchboard and accessories	42,380
20. Miscellaneous	13,900
21. Contingencies, incidentals and engineering..........	20,600
22. Buildings:	
One brick and stone, 59 by 233 ft. (about).	
One brick and stone, 75 by 194 ft. (about).	
Total, about 29,295 sq. ft.	108,150
Grand total	$626,248

The land on which this power station stands is 200 by 300 ft. = 60,000 sq. ft., or about twice the area actually occupied by the buildings. This land was appraised at $37,500, or about 62 ct. per sq. ft., which is included under Real Estate.

Since the capacity of this plant is 5,500 kw., we obtain the cost per kw. by dividing each of the foregoing 26 items by 5,500.

1. Machinery foundations	$ 4.77
2. Boilers and settings	8.07
3. Coal and ash building appar.	1.26
4. Coal storage bins and chutes	1.20
5. Grates and stokers	2.40
6. Breeching connections	0.54
7. Stack	2.10
8. Feed water heaters	0.27
9. Purifiers	0.57
10. Intake tunnels	3.46
11. Condensing equipment	3.00
12. Circulating and boiler feed pumps	0.60
13. Piping, valves and covering	8.00
14. Engines	23.64
15. Generators	15.82
16. Boosters	1.93
17. Crane	0.80
18. Generator and switchboard cables	1.82
19. Switchboard and accessories	7.71
20. Miscellaneous	2.53
21. Contingencies and engineering	3.75
22. Building	19.66
Total	$113.90
Land	6.82
Total	$120.72

If we take ¾ of the foregoing, we have the approximate cost per horsepower.

The depreciated or present value assigned to this power plant, Station A, was as follows:

1. Machinery foundation	$ 26,250
2. Boilers and settings	30,907
3. Coal and ash appar.	3,890
4. Coal storage bins	4,650
5. Grates and stokers	9,345
6. Breeching connections	1,656
7. Stack	8,464
8. Feed water heaters	941
9. Purifiers	1,170
10. Intake tunnels	19,050
11. Condensing equipment	9,116
12. Circulating and feed pumps	1,971
13. Piping, valves and covering	35,144
14. Engines	94,452
15. Generators	73,871
16. Boosters	7,963
17. Crane	2,370
18. Generator and switchboard cables	8,290
19. Switchboard and accessories	35,634
20. Miscellaneous	6,917
21. Contingencies and engineering	12,480
22. Building	108,150
Total	$502,681

The plant was about 14 yr. old, with the exception of the 4 Sterling boilers (total 1,416 hp.), the 2,500 hp. engine, and the 2,000 hp. Cochran heater, which were about 4 yr. old; also the 3 generators, which were about 6 yr. old. A comparison of the above depreciated values with the cost of reproduction new will indicate the rates of depreciation allowed. Including buildings and ma-

chinery foundations (Items 1 and 22), it will be seen that the average depreciated value is 80.3% of the cost of reproduction; but, deducting items 1 and 2, the percentage is 74.8%. This last would indicate an average depreciation of nearly 2% per annum.

We pass now to the power plant equipment of Station B, having a rated capacity of 8,400 kw. and an estimated cost per kw. slightly less than for Station A. The cost of reproduction new was as follows:

1. Machinery foundations	$ 32,619
2. Boilers and settings:	
8 Stirling boilers, 250 h.p. each	
8 Stirling boilers, 300 h.p. each.	
8 Stirling boilers, 350 h.p. each.	
Total	65,652
3. Coal and ash building apparatus	11,489
4. Coal storage bins and chutes	10,942
5. Grates and stokers:	
20 Murphy furnaces and stokers.	
4 Detroit furnaces and stokers.	
Total	21,884
6. Breeching and connections	4,924
7. Stacks:	
Two brick stacks, 195 ft. above ground, 10-ft. flue	24,884
8. Feed water heaters:	
2 Cochran, each 2,500 h.p.	4,500
9. Economizers:	
Green fuel economizers, connection with 16 Stirling boilers (4,400 h.p.)	22,377
10. Intake tunnels	18,900
11. Condensing equipment:	
1 G. F. Blake condenser.	
1 Baragwanath condenser.	
4 M. T. Davis condensers (style 6).	
Total	16,200
12. Circulating and boiler feed pumps:	
4 Davidson feed pumps, No. 7½.	
1 Worthington duplex.	
Total	5,471
13. Piping, valves and covering	43,150
14. Engines:	
2 Filer & Stowell, cross compound, condensing, 2,250 h.p. each.	
2 E. P. Allis Co., ditto, 1,200 h.p. ea.	
2 E. P. Allis Co., ditto, 600 h.p. ea.	
Total	129,150
15. Generators:	
2 Westinghouse, 1,500 kw. each.	
2 Walker Mfg. Co., 800 kw. each.	
2 Walker Mfg. Co., 400 kw. each.	
Total	86,050
16. Turbo-generator plant:	
1 Westinghouse, 3,000 kw. generator.	
1 Parson's steam turbine, 4,500 h.p.	
1 Baragwanath jet condenser (42-in.)	
1 Baragwanath centrifugal pump (18-in.)	
Exciter, induction motor, engine, etc.	
Total	146,500
17. Boosters:	
2 General Electric generators.	
1 Westinghouse motor, 250 kw.	
4 Westinghouse generators, 500 each.	
4 Westinghouse motors, 540 each.	
1 Westinghouse exciter generator, 12½ kw.	
Total	5,784

18.	Crane: Hand operated, 51-ft. span, 15-ton capacity	$ 4,320
19.	Generator and switchboard cables	13,542
20.	Switchboard and accessories	9,898
21.	Miscel. apparatus and tools	17,315
22.	Contingencies, incidentals and engineering	21,450
23.	Building: About 54,800 sq. ft.	138,080
	Grand total	$855,080

The land assigned to this power plant covers about 168,000,000 sq. ft. (or about three times the area occupied by the buildings), and its appraised value is $147,669.

Dividing each of the above 23 items by 8,400 we have the following cost of the plant per kw.:

		Per kw.
1.	Machinery foundations	$ 3.88
2.	Boilers and settings	7.81
3.	Coal and ash handling appar.	1.37
4.	Coal storage bins and chutes	1.30
5.	Grates and stokers	2.60
6.	Breeching and connections	0.59
7.	Stacks (brick)	2.96
8.	Feed water heaters	0.54
9.	Economizers (for 2-3 of the boilers)	2.66
10.	Intake tunnels	2.25
11.	Condensing equipment	1.93
12.	Circulating and feed pumps	0.60
13.	Piping, valves and covering	5.14
14.	Engines	15.38
15.	Generators	10.25
16.	Turbo-generator plant	17.44
17.	Boosters	0.69
18.	Crane	0.51
19.	Generator and switchboard cables	1.61
20.	Switchboard and accessories	1.18
21.	Miscel. apparatus	2.06
22.	Contingencies and engineering	2.55
23.	Buildings	16.44
	Total	$101.79
	Land	17.58
	Grand total	$119.37

The depreciated or present value of this Station B is as follows:

1.	Machinery and foundations	$ 32,619
2.	Boilers and settings	43,743
3.	Coal and ash handling appar.	7,003
4.	Coal storage bins and chutes	8,754
5.	Grates and stokers	15,098
6.	Breeching and connections	3,774
7.	Stacks	19,547
8.	Feed water heater	3,575
9.	Economizers	11,750
10.	Intake tunnels	18,900
11.	Condensing equipment	10,530
12.	Circulating and feed pumps	3,421
13.	Piping, valves and covering	32,832
14.	Engines	95,720
15.	Generators	71 292
16.	Turbo-generator plant	146,500

17. Boosters	$ 3,145
18. Crane	2,350
19. Generator and switchboard cables	11,340
20. Switchboard and accessories	7,563
21. Miscellaneous appar.	14,589
22. Contingencies, incidentals and engrg.	14,240
23. Buildings	138,080
Total	$716,370

This is 83.5% of the cost of reproduction new. But if we deduct items 1, 10 and 23, the corresponding percentage is 79 1%.

The equipment of Station B was about 14 yr. old, with the following exceptions: 8 Sterling, 350 hp. boilers, about 2 yr. old; 2 Cochran heaters, about 1½ yr. old; 2 Filer & Stowell engines, 2,250 hp. ea., about 10 yr. old; 3 condensers, about 3 yr. old; 2 Westinghouse generators, 1,500 kw. ea., about 10 yr. old; brick stack, about 2 yr. old; turbo-generator plant, about 1½ yr. old. If we deduct the turbo-generator plant (item 16), as well as items 1, 10 and 23, the present value is 73.2% of the cost of reproduction new, which corresponds closely with the per cent. of depreciation assigned to Station A.

4. *Battery Stations.*— There are 2 battery stations, designated as *K* and *L*. Part of the machinery in Station *K* is owned by the Edison Illuminating Co. and is not included in the following appraisal of the cost of reproduction new:

Station K.

1 Electric Storage Battery Co.'s storage battery, 2,500 ampere-hour capacity, 260 cells of 67 plates ("G" type) per cell	$ 89,300
1 Western Electric booster, type "P-6," connected to a 300 h.p. motor	11,000
Switchboard and accessories	2,959
Battery and equalization station accessories	3,542
Tools	187
Furniture and fixtures	315
Heating	200
Stock	3,517
Buildings (53 by 113 ft.), lighting, etc.	15,000
Total	$126,021

The depreciated or present value is appraised at $110,575.

The cost of reproduction new of Station *L* is as follows:

Station L.

1 Electric Storage Co.'s storage battery, 2,000 ampere-hour, 250 cells of 53 plates ("G" type), per cell	$ 72,250
1 Western Electric booster, type "I-6," and a 200 h.p. motor	6,400
Switchboard connections	1,815
Battery and equalizing sta. accessories	2,391
Tools	342
Furniture and fixtures	98
Heating	287
Stock	12,652
Stationary testing insts.	296
Buildings (39 by 158 ft.) and lighting	5,700
Total	$102,231

The depreciated value is $89,912.

5. *Power Distribution.*— The cost of reproduction new of the power distribution system is as follows:

1. Iron Poles:

7,498 iron poles, various sizes, 4,395,946 lbs. at $2.75 per C. lbs.	$120,888.52
Labor erecting at $9.78	73,330.44
Total, iron poles	$194,218.96

2. Cedar Poles:

2,198 cedar poles, 30-ft., at $5.50	$12,089.00
201 cedar poles, 35-ft., at $7.25	1,457.25
9 cedar poles, 40-ft., at $10.25	92.25
1 cedar pole, 45-ft., at $12.50	12.50
2,409 cedar poles, labor at $4.00	9,636.00
Total, cedar poles	$23,287.00

3. Idaho Poles:

92 Idaho poles, 50-ft., at $14.25	$1,311.00
1 Idaho pole, 55-ft., at $16.00	16.00
20 Idaho poles, 60-ft., at $21.00	420.00
113 Idaho poles, labor at $5.35	604.55
Total, Idaho poles	$2,351.55

4. Northern Pine Poles:

73 Octagon Northern Pine poles, 28-ft., at $7.50	$ 547.50
112 Octagon Northern Pine poles, 30-ft., at $10.25	1,148.00
16 Octagon Northern Pine poles, 35-ft., at $12.50	200.00
201 poles, labor at $4.00	804.00
Total, Northern Pine poles	$2,699.50

5. Pole Tops and Guy Stubs:

2,540 Eye bolts, washers and fittings, various prices	$ 303.44
76 Eye bolts, various prices	7.59
12,053 Iron and wood pins	373.64
580 (3-pin) iron pole tops, at $3.65	2,117.00
2,804 Wood pole tops, at 50 cts.	1,402.00
68 Wood pole tops, with iron caps, at 75 cts.	51.00
11 Wood pole tops, with iron caps, at 85 cts.	9.35
2,437 Wood pole tops, with 1.5-in. iron pins, at 90 cts.	2,193.30
224 Iron pole tops, at 90 cts.	201.60
12 Iron pole tops, at 50 cts.	6.00
878 Iron pole tops, at 95 cts.	834.10
15 Iron pole tops, at $1.10	16.50
10 pole top extensions, at $2.80	28.00
14 Special insulated lamp pole tops, at $1.50	21.00
21 Cedar guy stubs, at $2.00	42.00
15,605 lbs. iron cut stubs, at $2.75	429.14
1,102 Locust pins, at 2 cts.	22.04
75 Maple pins, at 3 cts.	2.25
80 Iron pins, at 17 cts.	13.60
Total pole tops and stubs	$8,073.55

6. Iron Pole Strap Bands:

Various sizes and values	$6,067.77

7. Iron Crossarms:

342 No. 10 iron crossarms, at $3.50	$1,197.00
234 No. 20 iron crossarms, at $2.75	643.50
549 No. 20 iron crossarms, at $2.75	1,509.75

119 Ft. Wayne iron crossarms, at $2.20	$ 261.80
Labor erecting 1,244 iron crossarms, at $1.00	1,244.00
Total, iron crossarms	$4,856.05

8. Wood Crossarms:

378 2-pin maple crossarms, at 30 cts.	$ 113.40
1,806 4-pin maple crossarms, at 35 cts.	632.10
28 6-pin maple crossarms, at 60 cts.	16.80
Labor erecting 2,212 wood crossarms, at 50 cts.	1,106.00
Total, wood crossarms	$1,868.30

9. Insulators:

2,387 (500,000 cir. mils) shell top feeder insulators, at 70 cts.	$1,670.90
1,825 (1,000,000) shell top feeder insulators, at 50 cts.	1,460.00
474 (500,000) shell top corner insulators, at 90 cts.	426.60
210 (1,000,000) shell top corner insulators, at $1.00	210.00
1,932 Ohio brass clinch corner insulators, at 40 cts.	772.80
5,177 Feeder glass insulators, at 66 cts.	341.68
3,734 Wood strain insulators, at 20 cts.	746.80
875 Small Brooklyn strain insulators, at 60 cts.	525.00
5 Small double Brooklyn strain insulators, at 60 cts.	3.00
507 Large Brooklyn strain insulators, at 90 cts.	456.30
10 Large double Brooklyn strain insulators, at $2.00	20.00
214 (2/0) sectional insulators, at $3.75	802.50
97 Clinch top insulators, at 40 cts.	38.80
190 Ohio brass clinch top insulators, at 40 cts.	76.00
242 Top groove glass insulators, at 66 cts.	15.97
9 Mica Medbury insulators, at 50 cts.	4.50
802 No. 1 Giant strain insulators, at 35 cts.	280.70
6,972 No. 2 Giant strain insulators, at 25 cts.	1,743.00
2,470 Medbury spool insulators, at 20 cts.	494.00
676 Medbury feeder insulators, at 63 cts.	425.88
20 Special tower clamp insulators, at $2.20	44.00
Total, insulators	$9,758.43

10. Ears:

155 Double ears, 2/0, at 60 cts.	$ 93.00
4 Feed-in ears, at 60 cts.	2.40
297 Strain ears, at 61 cts.	181.17
Total, ears	$ 276.57

11. Anchor Rods, Turnbuckles:

253 Turnbuckles and rods, various sizes and prices	$ 154.90
167 Anchor rods, various sizes and prices	53.70
Total, anchor rods, etc.	$ 208.60

12. Arresters:

357 Lightning arresters, various prices	$2,295.51
48 Lightning arresters, various prices	208.15
Labor	680.40
Total, arresters	$3,184.06

13. Circuit Breakers:

10 (450-ampere) Westinghouse automatic circuit breakers, 600-volt, slate base, special box, at $40	$ 400.00
1 (800-ampere) Westinghouse automatic circuit breaker, 600-volt, slate base, special boxes	85.00
1 (1,200-ampere) hard automatic oil circuit breaker, 600-volt, special box, lamps, etc.	115.00

1 (450-ampere) Westinghouse automatic circuit breaker, slate base, special boxes	$ 40.00
Labor on circuit breakers	115.50
Total, circuit breakers	$ 755.50

14. Bolts, Screws, Washers, Chairs:

26,196 Machine bolts, various sizes and prices	$ 261.96
2,503 Carriage bolts, various sizes and prices	21.28
6,975 Lag screws, various sizes and prices	121.37
166 Pounds of washers, various sizes and prices	10.00
1,358 Chairs, various sizes and prices	1,874.30
Total, bolts, etc.	$2,288.91

15. Switches:

14 (400-ampere) 600-volt, G. E. switches, slate base, at $4	$ 56.00
2 (400-ampere) 600-volt switches, G. E., S. P. D. T., at $10	20.00
7 (1,200-ampere) 600-volt switches, G. E., S. P. D. T., at $16.88	118.16
11 (1,200-ampere) 600-volt switches, Anderson, at $16	176.00
21 (600-ampere) 600-volt switches, G. E., at $10	210.00
22 (600-ampere) 600-volt switches, Anderson, at $9.50	209.00
1 (600-ampere) 600-volt switch, G. E., S. P. D. T., at $14	14.00
1 Perkins 600-volt switch	.90
2 Westinghouse cut-out switches, at $7.50	15.00
16 No. 2 steel motor cut-out switches, at $6.25	100.00
21 cut-out switches, at $7.50	157.50
1 (600-ampere) G. E. switch, at $10.00	10.00
Labor	623.56
Total, switches	$1,710.12

16. Switch Boxes and Fuses:

14 Pine record boxes, at $1.85	$ 25.90
2 Feeder dividing blocks, at 50 cts.	1.00
2 (30-ampere) 600-volt fuse boxes, leather cover, at $2.25	4.50
20 Switch boxes, average $5.50	110.00
16 15-ampere Noark fuses, at 57 cts.	9.12
15 Switch boxes, 6 by 6 by 18-ins., at $4.25	63.75
3 Switch boxes, 6 by 6 by 18-ins., at $3.50	10.50
1 Switch box, 8 by 12 by 30-ins.	6.65
49 Switch boxes, 9 by 10 by 30-ins., at $5.50	269.50
2 Switch boxes, 40 by 24 by 10-ins., at $5.50	11.00
1 Brass switch lock, at 75 cts.	.75
Labor	22.10
Total, switch boxes	$ 534.77

17. Miscellaneous Iron Fittings:

40 0.5-in. by 7-ft. lightning arrester rods	$ 26.00
25 Trolley rods, 0.625-in. by 9-ft. 9 ins.	25.00
1 Truss rod, 0.75-in. by 24 ft.	6.00
2 Truss rods, 0.5-in. by 1-ft.	1.00
188 ft. iron truss rods, 0.75-in.	5.65
26 ft. iron truss rods, 0.5-in.	.35
1 0.5-in. by 5-ft. iron rod	1.07
13 Iron rods and braces, various sizes	13.45
1 0.75-in. by 10-ft. special truss rod	1.80
3 Trolley sign rods, 0.625-in. by 9.75-ins.	3.00
Miscellaneous labor	4.00
1,002 Crossarm braces	60.12
805 1.25-in. by 24-in. galvanized crossarm braces	48.30

78 Corner iron "U" clamps	$ 113.10
6 0.5 by 3 by 8-in. clamps	6.60
6 0.5 by 3 by 6-in. clamps	6.00
162 0.5 by 4 by 5-in. "U" bands	81.10
52 ft. 0.375 by 8-in. band iron	10.61
4 8 by 30-in. "U" bands	14.00
6 0.5 by 3 by 8-in. double bands	4.50
6 0.5 by 3 by 6-in. double bands	3.90
45 5-in. iron pole bands	42.75
4 0.375 by 1.75-in. by 3 ft. strap bands	6.00
2 0.5 by 8-in. by 3-ft. strap bands	3.50
2 0.5 by 3 by 24-in. iron plates	4.80
22 0.5 by 4 by 4-in. iron plates	4.40
52 0.375 by 8 by 10-in. iron plates	18.20
214 0.5625 by 9-in. iron pole steps	6.42
5 0.25 by 4-in. by 3-ft. 9-in. iron straps	3.75
2 Wrought iron straps, 0.5 by 0.5-ins., 15 ins. square	2.50
Total, miscellaneous fittings	$ 527.87

18. Wood Braces:

154 Pieces wood braces, various sizes and prices	$ 219.20
101 ft. b. m. Norway pine, various sizes, at $36 per M.	3.64
Total, wood braces	$ 222.84

19. Trolley Signs:

138 Trolley signs, 9 by 18-in. sheet iron	$ 138.00
16 "F" signs, 0.625 by 8-in. sheet iron	8.00
1 Illuminating sign	26.00
Labor	234.05
Total, trolley signs	$ 406.05

20. Trolley Brackets:

34 Flexible pole trolley brackets	$ 66.30
195 Straight line trolley brackets	487.50
7 Single pin side brackets	1.05
Total, trolley brackets	$ 554.85

21. Brackets:

7 Single arm trolley brackets	$ 13.65
5 Tower feeder brackets	25.00
13 Special iron extra feeder brackets	45.50
96 Single pin side brackets, at 15 cts.	14.40
26 Double pin side brackets, at 75 cts.	19.50
72 Wooden side brackets	1.01
449 Lag brackets, at 21 cts.	94.29
Total, brackets	$ 213.35

22. Hangers:

6,720 Straight line hangers, at 45 cts.	$3,024.00
1,105 Feed-in hangers, at 67 cts.	740.35
Total, hangers	$3,764.35

23. Wooden Trolley Troughs:

Materials	$ 753.35
Labor	1,486.75
Total, wooden trolley troughs	$2,240.10

24. Special Feeder and Trestle Constr.:

Total at 35 places	$6,012.00

25. Overhead Positive Feeder System:

T. B. Cable	Miles	Pounds
1,000,000	50.42	978,164
800,000	6.09	96,163
750,000	10.47	156,000
600,000	2.95	34,766
500,000	88.35	883,549
400,000	7.60	62,342
350,000	1.34	9,496
300,000	42.98	266,441
300,000 — Aluminum	0.11	303
250,000	3.24	16,875
4/0 T. B. cable	44.16	178,839
4/0 Bare cable	1.68	5,679
3/0 T. B. cable	4.30	14,292
2/0 T. B. cable	.99	2,617
2/0 Bare cable	1.61	3,427
1/0 T. B. cable	0.70	1,506
Total	266.99	2,710,459
2,710,459 lbs. copper		$486,313.62

26. Miscellaneous Articles:

1,101 hexagon head cup screws at $0.51	$ 56.15
5 wood rollers at $0.75	3.75
42 pounds lock washers	5.51
20 span wire take-ups at $0.25	7.50
4 3-in. porcelain knobs at $0.02	.08
136 No. 4 porcelain knobs at $0.01	1.36
154 No. 1 porcelain knobs at $0.015	2.31
15 ft. 1 in. gas pipe at $0.05	.75
30 feet 0.5-in. circular loom at $0.05	1.50
1 16-in. by 3-in. C. I. pole guard	7.00
1 0.25-in. by 2-in. by 3 ft. angle iron, per lb., $0.035	.25
12 Pieces 0.25-in. by 1.125-in. by 7-in. copper, per lb., $0.35	4.20
27 Pieces C. I. lining blocks, per lb., $0.04	50.63
2,690 ft. 4-ply 10-in. rubber belting at $0.48	1,291.20
154 1-in. by 18-in. wood screws, per gr., $0.31	.33
2 0.5-in. by 6-in. iron clevices, at $0.45	.90
109 wooden feed rollers at $0.75	81.75
1 0.5-in. by 4-ft. eye bolt. per C. $9.80	.10
115 assorted eye bolts, 12-ins. to 16-ins. long, per 100 lbs., at $4.41	5.07
1 14-in. insulated eye bolt	.37
13 14-in. insulated eye bolts at $0.37	4.81
1,201 assorted eye bolts, 0.625-in. by 16-in., per 100 lbs., at $6.45	79.15
1 special made wall plate, 0.5-in. by 4-in. by 30-in.	3.50
1 special made wall plate, 1-in. by 6-in. by 36-in.	4.25
63 ft. 4-ply 10-in. rubber belting at $0.59	37.17
Total, miscellaneous	$1,649.59

27 Span Wire:

290 ft. double galvanized span wire, 0.25-in., at $0.75 per 100 ft.	$ 2.18
240,530 ft. double galvanized span wire, 0.3125-in., at $1.00 per 100 ft.	2,405.30
915 ft. double galvanized span wire, 0.375-in., at $1.20 per 100 ft.	10.98
300 ft. double galvanized span wire, 0.5-in., at $1.80 per 100 ft.	5.40
37,287 ft. double galvanized guy wire, 0.25-in., at $0.75 per 100 ft.	279.65
70,790 ft. double galvanized guy wire, 0.3125-in., at $1.00 per 100 ft.	707.90

50,172 ft. double galvanized guy wire, 0.375-in. at $1.20 per 100 ft.	$ 602.06
34,627 ft. double galvanized guy wire, 0.5-in., at $1.80 per 100 ft.	623.29
92 ft. double galvanized guy wire, 0.75-in., at $5.00 per 100 ft.	4.60
267 ft. wire cable, 1-in., at $0.19 per ft.	50.73
625 ft. iron wire, No. 6, at $0.04 per lb.	2.39
75 ft. iron wire, No. 10, at $0.04 per lb.	.13
5,068 ft. barbed wire, per roll of 80 rods, at $1.25	4.89
Labor erecting 9,010 spans at $1.00 each	9,010.00
Total, Span Wire	$13,709.41

28. Miscellaneous Copper:

63,620 lbs. (about), at 17 cts. per lb.	$10,815.40

29. Track and Pipe Negatives:

78,050 lbs. (about) copper for track, at 17 cts.	$13,266.68
Labor on same	769.40
66,800 lbs. (about) copper for pipe neg., at 17 cts.	11,353.91
Labor on same	823.63
Total, Track and Pipe Negatives	$26,173.62

30. Overhead Special Work:

88,990 lin. ft. 0.25-in. galvanized iron span wire at $0.75 per 100 ft.	$ 667.43
69,400 lin. ft. 0.3125-in galvanized iron span wire at $1.00 per 100 ft.	694.00
1,695 lin. ft. 0.375-in. galvanized iron span wire at $1.20 per 100 ft.	20.34
4,151 lin. ft. 2/0 copper wire, 1,673 lbs., at $0.18 per lb.	301.14
467 overhead trolley switches, at $7.50	3,502.50
37 insulated overhead trolley cross-overs, at $4.38	162.06
222 metallic overhead trolley cross-overs, at $4.00	888.00
1,851 single wire pull-overs, at $0.40	740.40
94 single, double wire pull-overs, at $0.58	54.52
1,493 double, single wire pull-overs, at $0.60	895.80
66 double, double wire pull-overs, at $0.93	61.38
377 hangers at $0.45	169.65
114 No. 1 strain insulators at $0.35	39.90
1,894 No. 2 strain insulators at $0.25	473.50
34 large Brooklyn strain insulators at $0.90	30.60
317 small Brooklyn strain insulators at $0.60	190.20
107 strain ears at $0.61	65.27
697 wood breaks at $0.20	139.40
480 collars at $0.15	72.00
104 Meadbury composition at $0.20	20.80
158 eye bolts at $0.08	12.64
117 iron rings at $0.025	2.92
31 turnbuckles at $0.50	15.50
120 "V" guards at $0.50	60.00
2 double and single trolley metallic crossings at $5.50	11.00
9 double and single trolley insulator crossings at $7.27	65.43
Labor erecting 293 layouts	22,277.09
Total, Overhead Special Work	$31,633.47

31. Underground Return System:

Various negative connections	$47,009.11
Positive feeder lines	6,388.30
Total, Underground System	$53,397.41

32. Underground Pipe Connections:

85 connections	$ 7,122.86

33. Trolley Wire (2/0):

201.91 miles plus 1% for sag = 1,075,640 lin. ft., at 0.403 lbs. = 433,481 lbs. copper	$78,026.58
Labor	7,023.42
Total, Trolley Wire	$85,050.00

34. Overhead Line Material in Car Stations, Shops and Yards:

Material	$ 6,826.78
Labor	9,948.00
Total	$16,776.78

35. Telephone System:

Materials, No. 10 iron wire, 546,023 ft.	$ 4,231.85
Labor, 51.706 miles circuit (or 103.412 miles single wire) at $15	775.59
Total, Telephone System	$ 5,007.44

36. Potential Lines:

Potential wires and material from power station "A" to Adams avenue.	
Total for material and labor	$ 110.06
Total for material and labor from battery	270.48
Total, Potential Lines	$ 380.54

37. Cross Bonding:

347 Single track cross bonds at $4.19	$ 1,453.93
343 Double track cross bonds at $9.06	3,107.58
Total, Cross Bonding	$ 4,561.51

38. Straight Track Bonding:

490	lin. ft. 500,000 c. m. T. B. W. P. copper cable	$ 157.76
31,520	lin. ft. 2/0 copper wire, 12,932 lbs.	2,286.15
27,098	42-in. 4/0 flexible copper bonds	21,678.40
1,995	36-in. 4/0 flexible copper bonds	1,396.50
2,136	31-in. 4/0 flexible copper bonds	1,324.32
27,035	10-in. form 8 flexible copper bonds	20,276.25
10,769	"U" copper bonds	7,538.30
110	21-in. 4/0 copper stubs	55.00
75	lbs. No. 14 copper wrapping wire	18.75
62	lbs. solder	11.47
4,302	4/0 solid copper bonds	3,441.60
40	36-in. 4/0 solid copper bonds	28.00
80	36-in. riveted copper bonds	37.60
5,256	42-in. riveted copper bonds	2,890.80
1,028	36-in. 2/0 channel pin copper bonds	246.72
170	miles track, 352 joints per mile (2 rails), 59,840 rail joints	22,405.78
	Total, Straight Track Bonding	$83,793.40

39. Special Work Bonding:

166,052	lin. ft. 2/0 copper wire, 68,321.4 lbs., at $0.18	$12,043.75
13,472	42-in. 4/0 flexible copper bonds at $0.80	10,777.60
3,840	36-in. 4/0 flexible copper bonds at $0.70	2,688.00
347	32-in. 4/0 flexible copper bonds at $0.62	215.14
352	36-in. 3/0 flexible copper bonds at $0.65	228.80
554	10-in. 4/0 figure "S" copper bonds at $0.37	205.08
3,327	21-in. 4/0 copper stubs at $0.50	1,663.50
1,047	18-in. 4/0 copper stubs at $0.45	471.15

70	16-in. 4/0 flexible copper stubs at $0.40	$ 28.00
1,807	lin. ft. No. 14 copper wrapping wire, 22.5 lbs., at $0.25	5.63
2,434	lbs. solder at $0.185	450.29
105	42-in. 4/0 solid copper bonds at $0.80	84.00
220	42-in. 2/0 channel pin copper bonds with 2 pins at $0.87	191.40
761	36-in. 2/0 channel pin copper bonds with 2 pins at $0.78	593.58
89	30-in. 2/0 channel pin copper bonds with 2 pins at $0.67	59.63
55	24-in. 2/0 channel pin copper bonds with 2 pins at $0.61	33.55
63	2/0 channel pin copper plugs at $0.10	6.30
58	2/0 copper " U " bonds at $0.70	40.60
30	4/0 flexible copper soldered bonds at $0.52	15.60
258	lin. ft. 1,000,000 c. m. T. B. W. P. copper cable, 948 lbs., at $0.17	161.16
158	lin. ft. 4/0 insulated cable, 126.4 lbs., at $0.17 ..	21.49
	Total, special Bonding	$29,984.25

40. Equalizing Stations:

11 stations	$ 21,737.08
Total of Items 1 to 40	$1,154,187.43
41. Contingencies	57,709.37
Grand total	$1,211,896.80

Dividing each of the above 41 items by 183.34, we have the following costs per mile of all track.

	Per mile of track
1. Iron poles (40.9 poles)	$1,059.30
2. Cedar poles (13.1 poles)	127.00
3. Idaho poles (0.6 poles)	12.80
4. Northern pine poles (1.2 poles)	14.50
5. Pole tops and guy stubs	44.00
6. Iron pole strap bands	33.10
7. Iron cross arms	26.50
8. Wood cross arms	10.20
9. Insulators	53.20
10. Ears	1.50
11. Anchor rods, turnbuckles	1.10
12. Lightning arresters	17.40
13. Circuit breakers	4.10
14. Bolts, screws, washers, chairs	12.50
15. Switches	9.30
16. Switch boxes and fuses	2.90
17. Miscellaneous iron fittings	2.90
18. Wood braces	1.20
19. Trolley signs	2.20
20. Trolley brackets	3.00
21. Brackets	1.20
22. Hangers	20.50
23. Wooden trolley troughs	12.20
24. Special feeder and trestle construction	32.80
25. Overhead positive feeder system	2,652.00
26. Miscellaneous	9.00
27. Span wire	74.70
28. Miscellaneous copper	59.00
29. Negative tracks and pipe feeders	142.70
30. Overhead special work	172.50
31. Underground return system	291.20
32. Underground pipe connections	38.80

33. Trolley wire	$463.80
34. Overhead material in car stations, etc.	91.50
35. Telephone lines	27.30
36. Potential lines	2.10
37. Cross bondings	24.90
38. Straight track bonding	457.00
39. Special work bonding	163.50
40. Equalizing stations	118.60
Total	$6,295.00
41. Contingencies	314.70
Grand total	$6,609.70

The depreciated or present value of the power distribution system is as follows:

1. Iron poles	$ 174,797.06
2. Cedar poles	11,643.50
3. Idaho poles	1,175.78
4. Northern pine poles	674.88
5. Pole tops and guy stubs	7,260.96
6. Iron pole strap bands	5,764.32
7. Iron cross arms	4,370.45
8. Wood cross arms	1,494.64
9. Insulators	8,309.01
10. Ears	248.91
11. Anchor rods, turnbuckles	198.17
12. Lightning arresters	2,865.66
13. Circuit breakers	679.95
14. Bolts, screws, washers, chairs	2,174.47
15. Switches	1,539.11
16. Switch boxes and fuses	481.29
17. Miscellaneous iron fittings	482.20
18. Wood braces	189.44
19. Trolley signs	365.45
20. Trolley brackets	499.36
21. Brackets	192.02
22. Hangers	3,387.92
23. Wooden trolley troughs	1,904.08
24. Special feeder and trestle construction	6,012.00
25. Overhead positive feeder system	461,997.93
26. Miscellaneous articles	1,495.31
27. Span wire	10,973.34
28. Miscellaneous copper	10,274.63
29. Negative tracks and pipe feeders	24,864.94
30. Overhead special work	26,989.23
31. Underground return system	53,397.41
32. Underground pipe connections	6,410.57
33. Overhead line material, 2/0 trolley wire	68,040.00
34. Overhead line material in car-stations, etc.	14,260.24
35. Private telephone lines	4,256.32
36. Potential lines	323.46
37. Cross bondings	3,877.28
38. Straight track bonding	71,224.39
39. Special work bonding	25,486.61
40. Equalizing stations	16,696.42
Total of items	$1,037,278.71
41. Contingencies	50,784.25
Total	$1,088,062.96

This is 89.7% of the cost of reproduction new.

In determining the depreciation, from 10 to 15 poles per mile were uncovered at the ground line.

Calibrations (horizontal and vertical) were made of the trolley wire, and the feed wire was inspected in different locations.

The trolley wire system is as follows:

	Miles
Single trolley span wire constr., double track	117.28
Single trolley span wire constr., single track	43.22
Double trolley span wire constr.	26.21
Single trolley span wire constr., three tracks	0.41
Single trolley center pole bracket constr., double track	1.29
Single trolley span wire constr. in car yards	13.54
Total	201.95

6. *Track.*— There are 21 different types of rail and 95 different forms of track construction. The following is a summary of the 21 types of rail used, not including special track work:

	Miles
2⅞ ins. 25 -lb., T	0.1763
4¼ ins. 56 -lb., T	1.3986
4¼ ins. 60 -lb., T	1.5320
4½ ins. 66½-lb., TG	0.3831
4½ ins. 67 -lb., T	0.0437
4⅝ ins. 70 -lb., T	1.36
6 ins. 72 -lb., T	0.0693
6 ins. 77 -lb., GG	11.5437
6 ins. 78 -lb., TG	0.446
6 ins. 82 -lb., TG	0.032
7 ins. 70 -lb., T	2.893
7 ins. 72 -lb., GG	0.967
7 ins. 85 -lb., GG	47.53
7 ins. 86 -lb., GG	11,8125
7 ins. 91 -lb., T	8.63
7 ins. 91 -lb., GG	4.554
7 ins. 95 -lb., GG	1.1222
8 ins. 95 -lb., GG	3.048
9 ins. 90 -lb., GG	4.574
9 ins. 94 -lb., GG	0.276
9 ins. 98 -lb., GG	58.49
Total	160.8814

T = "T" rail.
TG = Tram girder rail.
GG = Girder grooved rail.

The total mileage of single track is as follows:

	Miles
Single track	167.489
Special Y's, turnouts, etc.	2.922
Total trackway	170.411
Car stations, yards, etc.	12.930
Total track	183.341

Most of the rails were laid in 1895–1896.

Including the differences in paving, there are 204 different types of track construction. A detailed estimate was made for each type, based on the following unit prices:

Excavation:	Per cu. yd.
Earth and sand trench work	$0.50
Earth and sand	0.35
Drain tile	0.35
Haul:	
Earth and sand	$0.80
Grading:	
Earth and sand on street	$0.25
Track Foundation:	
Earth filling	$0.22
Gravel	1.80
Crushed stone	1.95
Concrete	4.50
Cushion:	
Sand	$1.50
Ties:	Each
White oak 6 ins. by 7 ft.	$0.75
White oak 5 ins. by 11 ins. by 9 ft. 10 ins.	1.44
White oak 6 ins. by 10 ins. by 6 ft. 8 ins.	1.18
Cedar and pine 6 ins. by 8 ins. by 8 ft. 0 ins.	0.65
Cedar and pine 6 ins. by 8 ins. by 6 ft. 10 ins.	0.60
Angle iron ⅜-ins. by 2½ ins. by 6 ft. 0 ins.	1.09
Channel iron 7 ins. by 7 ft. 0 ins.	2.52
Bar iron ½ in. by 1½ in. by 6 ft. 0 in.	0.42
Tie clips	0.22
Drain:	Per lin. ft.
Soft tile	$0.04½
Rail:	Per ton
"T"	$31.75
"T"	33.75
Girder groove	40.00
Plain girder	40.00
Tram	40.00
Spikes:	Per keg
Standard spikes	$4.00
Bolts:	Per keg
Bolts and nuts	$4.75
Tie Rods:	Each
¾ in. by 5 ft. 2 ins. round	$0.25
⅜ in. by 1½ in. flat	.67
Joints:	Per pair
4 hole strap plates	$0.07⅔
4 splice plates 20 ins.	.76½
4 hole splice plates 20 ins.	.34⅓
4 hole splice plates 20 ins.	.57
4 hole splice plates 20 ins.	.22⅞
4 hole splice plates 24 ins.	.55½
4 hole splice plates 27 ins.	.68¾
4 hole splice plates 44 ins.	1.34
6 hole splice plates 28 ins.	1.07
6 hole splice plates 26 ins.	.65
10 hole splice plates 36 ins.	.94
10 hole splice plates 36 ins.	.907
6 hole splice plates 36 ins.	.835
12 hole splice plates 32 ins.	1.31
4 hole continuous plates	1.62½
4 hole continuous plates	1.36⅛

4 hole continuous plates 24 ins.	$1.71 3/10
4 hole continuous plates 20 ins.	1.42½
4 hole continuous plates 20 ins.	1.38
4 hole continuous plates 20 ins.	1.54½
4 hole continuous plates 26 ins.	2.53¾
6 hole continuous plates 26 ins.	2.53¾
8 hole continuous plates 30 ins.	4.65
8 hole continuous plates 22 ins.	4.08
American rail joint	2.50
Cast weld joint, each	3.00
Rail straps	0.51½

Retaining wall:	Per cu. yd.
Concrete	$6.50

The unit prices used for the special track work are as follows:

Nine-inch:	Cost in place
Plain layout (switch, mate and frog)	$390.90
Hard center layout (switch, mate and frog)	467.70
Hard center diamond switch ends	807.05
Plain street crossing	243.70
Hard center street crossing	333.30
Plain frog	96.25
Hard center frog	126.33
2-point hard center frog	246.06
3-point hard center frog	307.70
Hard center mate	166.65
Plain tongue switch	160.50
Hard center tongue switch	185.85
Curved or guard rail (per lin. ft.)	2.18
Switch lock boxes	32.00
Switch spring boxes	8.96
Seven-inch:	
Plain layout (switch, mate anod frog)	$358.90
Hard center layout (switch, mate and frog)	435.70
Plain diamond switch ends	410.25
Hard center diamond switch ends	551.05
Plain street crossings	224.50
Hard center street crossings	314.10
Plain frog	86.01
Hard center frog	11.55
2-point hard center frog	224.30
3-point hard center frog	281.90
Plain mate	130.81
Hard center mate	156.41
Plain tongue switch	147.45
Hard center tongue switch	173.05
Curved or guard rail (per lin. ft.)	2.02
Six-inch:	
Plain layout (switch, mate and frog)	$320 50
Hard center layout (switch, mate and frog)	403.70
Hard center street crossing	307.70
Plain frog	77.05
Hard center frogs	102.65
2-point plain frog	153.85
3-point hard center frog	262.70
2-point hard center frog	205.10
Plain mate	115.45
Hard center mate	141.05
Plain tongue switch	128.25
Hard curved switch	160.25
Curved or guard rail (per lin. ft.)	1.83
100-lb. "T" Rail:	
Combined steam and electric railway crossing	$499.00

80-lb. "T" Rail:

Combined steam and electric railway crossing straight	$410.60
Combined steam and electric railway crossing curved	442.60

70-lb. "T" Rail:

Plain frog	$ 57.85
Plain split switch	61.69
Curved or guard rail (per lin. ft.)	1.61

60-lb. "T" Rail:

Plain layout (switch, mate and frog)	$237.30
Plain street crossing	173.30
Plain frog	46.33
2-point frog	102.65
Plain switch	47.61
Curved or guard rail (per lin. ft.)	1.45

4¼-in. 56-lb. "T" Rail:

Combined steam and electric railway crossing, curved	$278.50
Plain frog	43.77
Split switch	47.61
Curved or guard rail (per lin. ft.)	1.45

4-in., 50-lb. "T" Rail:

Plain layout (switch, mate and frog)	$182.26
2-point plain frog	102.65
Plain mate	64.25
Plain switch	77.05
Curved or guard rail (per lin. ft.)	1.42

3¾-in., 45-lb. "T" Rail:

Plain layout (switch, mate and frog)	$182.26
Curved or guard rail (per lin. ft.)	1.42

The following are estimates of a few typical sections of track, per mile of single track:

4¼-in., 60-lb. "T" Rail on Cedar Ties, Dirt Construction:

1,776 cu. yds. earth excavation	$ 621.60
822 cu. yds. earth spread over street	205.50
954 cu. yds. earth replaced for track foundation and filling between ties	209.88
729 (6 ins. by 8 ins. by 7 ft.) white oak ties laid 15 to rail	546.75
1,911 (6 ins. by 8 ins. by 8 ins.) cedar ties, 15 to rail	1,242.15
94,286 tons 4¼ ins. 60-lb. "T" rail in 30-ft. lengths	3,182.15
31¼ kegs 9/16 ins. by 5½ ins. standard railroad spikes	125.00
255 pairs 20 ins. 4-hole spliced joint plates, 18 lbs. per pair	87.55
97 pairs 20 ins. 4-hole continuous joint plates	138.23
5⅞ kegs ¾ ins. by 3½ ins. joint bolts with nuts	27.91
1 mile track laying	1,375.00
Total	$7,761.72
Contingencies	776.17
Cost per mile	$8,537.89

6-in., 72-lb. plain girder rail on white oak ties, 6-in. Concrete Constuction:

977 cu. yds. earth and sand excavation	$ 341.95
977 cu. yds. earth and sand removed from street	781.60
818 cu. yds. broken concrete removed from street	818.08
818 cu. yds. 6-in. concrete for track foundation	3,681.00
38 cu. yds. sand cushion for tamping, lining and surfacing ties	57.00

2,640 (6 ins. by 8 ins. by 7 ins.) white oak ties, 15 to rail	$ 1,980.00
113,143 tons 6 ins. 72-lb. "T" rails in 30-ft. lengths, joints laid even and suspended between ties	4,525.72
31¼ kegs 9/16 ins. by 5½ ins. standard railroad spikes	125.00
352 pairs 28 ins. 6-hole splice joint plates, 56 lbs. per pair	376.64
11½ kegs ⅞ ins. by 3½ ins. joint bolts with nuts	54.63
1 mile of track laying	1,400.00
Total	$14,141.62
Contingencies	1,414.16
Cost per mile	$15,555.78

6-in., 77-lb. Girder Grooved Rail on White Oak Ties, 6-in. Concrete Construction:

1,304 cu. yds. earth and sand excavation	$ 456.40
1,304 cu. yds. earth removed from street	1,043.20
1,104 cu. yds. 6 ins. concrete for track foundation	4,968.00
28 cu. yds. sand cushion for tamping, lining and surfacing	42.00
528 (6 in. by 10 in. by 6 ft. 8 in.) white oak ties, 3 to rail	623.04
1,408 (6 ins. by 8 ins. by 7 ft.) white oak ties, 8 to rail	1,056.00
121 tons 6 ins. 77-lb. girder grooved rail in 30-ft. lengths, joints laid even and suspended between ties	4,840.00
23 kegs 9/16 ins. by 5½ ins. standard railroad spikes	92.00
1,232 ¾ ins. by 5 ft. 2 ins. round tie rods, 6 to rail, four ¾-in. nuts per rod	308.00
1 mile of track laying	1,400.00
352 cast welded joints	1,056.00
Total	$15,884.64
Contingencies	1,588.46
Cost per mile	$17,473.10

7-in. 85-lb. Girder Grooved Rails on White Oak Ties, 6-in. Concrete Construction:

1,200 cu. yds. earth and sand excavation	$ 427.70
1,222 cu. yds. earth removed from street	977.60
978 cu. yds. 6-in. concrete for track foundation	4,401.00
41 cu. yds. sand cushion for tamping, lining and surfacing ties	61.50
2,816 (6-in by 8-in. by 7-ft.) white oak ties, 16 to rail	2,112.00
133,571 tons 7-in 85-lb. girder grooved rails in 30-ft. lengths, joints laid broken and supported on ties	5,342.84
33⅓ kegs 0.5625-in by 5.5-in. standard railroad spikes	133.33
352 cast welded joints	1,056.00
704 0.75-in. by 5-ft 2-in. tie rods, four 0.75-in nuts per rod	176.00
1 mile of track laying	1,400.00
Total	$16,087.97
Contingencies	1,608.79
Cost per mile	$17,696.76

7-in., 85-lb. Girder Grooved Rail on White Oak and Cedar Ties, 6-in. Crushed Stone Construction:

1,338 cu. yds. earth and sand excavation	$ 468.30
1,338 cu. yds. earth removed from street	1,070.40
1,070 cu. yds. 6-in. crushed stone for track foundation	2,086.50
880 (6-in. by 8-in. by 8-ft) cedar ties laid 5 to rail	572.00
880 (6-in. by 8-in. by 7-ft.) white oak ties, 5 to rail	660.00
133,571 tons 7-in. 85-lb. girder grooved rail in 30-ft. lengths, joints laid broken and suspended between ties	5,342.84
20.875 kegs 0.5625-in. by 5.5-in. standard railroad spikes	83.50

352 pairs 36-in 10-hole splice joint plates 54.5 lbs. per pair	$ 330.88
25.125 kegs 1-in by 3.5-in. joint bolts with nuts	118.75
1 mile of track laying	1,400.00
Total	$12,133.17
Contingencies	1,213.31
Cost per mile	$13,346.48

7-in. 85-lb. girder grooved rail on angle. Iron Ties, 6-in. Concrete Construction:

318 cu. yds. earth and sand excavation	$ 111.30
318 cu. yds. earth removed from street	254.40
212 cu. yds. 6-in. concrete for track foundation	954.00
1,232 (0.375-in. by 2.5-in. by 6-in.) angle iron ties, 7 to rail	1,349.04
133,571 tons 7-in. 85-lb. girder grooved rail in 30-ft. lengths, joints laid broken and suspended between ties	5,342.84
2,464 pairs cast iron tile clips, 2 pair per tie with two 0.75-in. by 2.25-in. bolts per pair	550.09
352 pairs 36-in 10-hole splice joint plates, 54.5 lbs. per pair	330.88
25.125 kegs 1-in. by 3.5-in. joint bolts with nuts	129.34
1 mile of track laying	1,400.00
Total	$10,164.35
Contingencies	1,016.44
Cost per mile	$11,180.79

8-in. 95-lb. Girder Grooved Rail on Pressed Steel Channel Ties, Concrete Construction:

301 cu. yds. earth and sand excavation	$ 105.35
301 cu. yds. earth removed from street	240.80
160 cu. yds. 6-in. concrete for track foundation	720.00
1,232 (7-in. by 7-in.) pressed steel channel ties, bracket fastening, 7 to rail	3,113.88
149,286 tons 8-in. 95-lb. girder grooved rail in 30-ft. lengths, joints laid even and suspended between ties	5,971.44
352 pairs 22-in. 8-hole continuous plates	971.52
23 kegs 1-in. by 4⅜-in. joint bolts with nuts	109.25
1 mile of track laying	1,400.00
Total	$12,632.24
Contingencies	1,263.22
Cost per mile	$13,895.46

9-in., 98-lb. Girder Grooved Rail on Oak Ties, 8-in. Crushed Stone Construction:

1,761 cu. yds. earth and sand excavation	$ 616.35
82 cu. yds. earth excavation for 4-in. drain tile	28.70
1,843 cu. yds. earth removed from street	1,474.40
5,280 lin. ft. 4-in. drain tile	237.60
68 cu. yds. crushed stone for covering 4-in. tile	132.60
1,092 cu. yds. 8-in. crushed stone for track foundation	2,129.40
301 cu. yds. concrete for track foundation	1,354.50
1,760 (6-in. by 10-in. by 6-ft. 8-in.) white oak ties, 20 to rail	2,076.80
154 tons 9-in. 98-lb. girder grooved rail in 60-ft. lengths, joints laid broken and suspended between ties	6,160.00
20.875 kegs 0.5625-in. by 5.5-in. standard railroad spikes	83.50
352 0.75-in. by 5-ft. 2-in. tie rods, 4 to rail, four 0.75-in. nuts per rod	88.00
1 mile of track laying	1,400.00
176 cast welded joints	528.00
Total	$16,309.85

Contingencies	$ 1,630.98
Cost per mile	$17,940.83

9-in., 98-lb. Girder Grooved Rail on Pressed Steel Channel Ties, Concrete Construction:

345 cu. yds. earth and sand excavation	$ 120.75
345 cu. yds. earth removed from street	276.00
223 cu. yds. concrete for track foundation	1,003.50
1,232 (7-in. by 7-ft.) pressed steel channel ties, 7 to rail	3,113.88
154 tons 9-in. 98-lb. girder grooved rail in 30-ft. lengths, joints laid even and suspended between ties	6,160.00
352 pairs 32-in. 12-hole splice joint plates, 68.5 lbs. per pair	461.12
30.25 kegs 1-in by 3.5-in. joint bolts with nuts	143.69
1 mile of track laying	1,400.00
Total	$12,678.94
Contingencies	1,267.89
Cost per mile	$13,946.83

9-in., 98-lb. Girder Grooved Rail on Oak Ties, 6-in. Concrete Construction:

1,401 cu. yds. earth and sand excavation	$ 490.35
1,401 cu. yds. earth removed from street	1,120.80
1,119 cu. yds. 6-in. concrete for track foundation	5,035.50
30 cu. yds. sand cushion for tamping, lining and surfacing ties	45.00
1,936 (6-in. by 10-in. by 6-ft. 8-in.) white oak ties, 11 to rail	2,284.48
154 tons 9-in. 98-lb. girder grooved rail in 30-ft. lengths, joints laid even and suspended between ties	6,160.00
22.875 kegs 0.5625-in. by 5.5-in. standard railroad spikes	91.50
352 pairs 22-in. 8-hole continuous joint plates	1,436.16
23 kegs 1-in. by 4.375-in. joint bolts with nuts	109.25
1,056 0.75-in. by 5-ft. 2-in. round tie rods, 6 to rail, four 0.75-in. nuts per rod	264.00
1 mile of track laying	1,400.00
Total	$18,437.04
Contingencies	1,843.70
Cost per mile	$20,280.74

The following is a summary of reproduction new of the track:

1. Straight track (156.72 miles)	$2,534,565
2. Track in car stations and yards (12.93 miles)	116,686
3. Special and curved track (13.7 miles)	708,894
Total track	$3,360,145
4. Interlocking	31,442
5. Catchbasins (1,395)	22,725
6. Manholes (568)	16,482
7. Water hydrants (8)	590
8. Machinery, tools, track, stock, etc.	130,566
9. Division foremen's outfit	39,386
Total track, etc.	$3,601,336

Item 3 includes curved track and guard rails (for which there were 94,000 lin. ft. or 17.8 miles of rail), frogs, switches, crossings, and the necessary excavation, concrete and broken stone foundations. The unit prices used for curved track (previously given) appear to cover the cost of ties, track fastenings, etc. While, as pre-

viously stated, the "Special Y's, turnouts, etc.," occupied 2.922 miles of track, there is no definite statement as to the total mileage of curved and special track; but, if we subtract the 156.72 miles of straight track and the 12.93 miles of track in car stations and yards from the 183.34 miles of all track, we have 13.7 miles, which is probably the entire mileage of curved and special track.

Dividing each of the above 9 items by 183.34, we have the following cost per mile of track:

	Per mile
1. Straight track, 0.855 mile	$13,823
2. Track in car stations and yards, 0.070 mile	636
3. Special and curved, 0 075 mile	3,866
Total track	$18,325
4. Interlocking	171
5. Catchbasins	124
6. Manholes	90
7. Water hydrants	3
8. Tools, stock, etc.	712
9. Division foremen's outfits	215
Total	$19,640

It will be noticed that the straight track cost $16,170 per mile of straight track, and that the special track cost $51,750 per mile of special track. The amount of track stock, etc. (Item 8), is obviously more than normal.

The present value of track, etc., is $2,599,222, or 72.2% of the cost of reproduction new $3,601,336). It is stated by Mr. Barcroft that no very accurate determination of the condition of the ties was possible, and that no rail renewal records had been kept by the railway company. By consultation with the companies' trackmen an approximation to the condition of invisible parts of the track was arrived at.

"The company requested that $12,000 be added for rail inspection at the mills. No inspection of rails has ever been made, although contemplated in the future, and consequently the item has not been included."

Most of the rails had been laid 14 years prior to the appraisal, "and are generally in a run down condition."

7. *Rolling Stock.* There are 1,000 passenger cars, of which 250 are open cars and the rest closed. The average cost of reproduction new is:

Car body and truck	$2,278
Electrical equipment	1,187
Total	$3,465

We shall give the cost of several typical cars in detail, which are based upon the following unit prices. Closed double end car bodies for single trucks:

	f.o.b. factory
16 ft. length of body	$1,100
18 ft. length of body	1,200

	f.o.b. factory
20 ft. length of body	$1,300
21 ft. length of body	1,350
22 ft. length of body	1,400
23 ft. length of body	1,450
24 ft. length of body	1,500
25 ft. length of body	1,550

To these prices of car bodies $30 to $32 is added for freight to Detroit. The above prices include the following and all other minor items installed:

Monitor Roof
Hood
Platform
Steps
Hangers
Glass
Gongs
Bells
Straps
Sanders
Signs
Switch Iron
Curtains
Ceiling
Trimming
Headlight
Hand Bells
Finishing
Cords and hangers
Lighting equipment
Register fixtures

Closed cars (body only) double truck —

	f.o.b. factory
28 ft. closed single end	$1,910
29 ft. closed single end	2,085

Open cars (body only) single truck, double end, reversible.

	f.o.b. factory
10 bench, 4 stationary against bulkheads	$1,000
9 bench, 2 stationary against bulkheads, all inside	1,000
10 bench, 2 stationary against bulkheads, all inside	1,100
11 bench, 3 stationary against bulkheads, 8 inside	1,150
Open car (body only), double truck, single end.	
14 bench, 4 stationary against bulkheads, 10 reversible, f.o.b. factory	$1,450
14 bench, 4 stationary against bulkheads, 10 reversible, f.o.b. Detroit	1,490

The above prices include the following and all other minor items installed:

Switch iron
Bells
Veneer ceiling
Chipped glass, D. S. A.
Push buttons
Drop guard on grab handles each side
Bulkhead with sashes at each end
Folding running board on each side
Incandescent headlights
Open platforms with dashers
Chain guard on each side
Lighting equipment
Printed duck curtains to floor
Cherry and ash seats with slat or spindle backs
Gongs
Ash finish
Bronze trimmings
Vestibule signs
Bulkhead seats

Additional equipment —

Stove	$25.00
Hot air heater	40.00
Electric heater	30.00
Truck, Brill 21-E	275.00
Truck, Dupont, 7,000 lbs.	350.00
Storage air brake trucks, complete $180 to	205.00
Fenders, Detroit	30.00
Fenders, Eclipse	25.00
Track scrapers, per pair	15.00
Platform gates $4 to	5.00
Installation of electrical equipment	40.00
Trolley retrievers	12.00
Push buttons and bells	10.00
Sterling registers, Nos. 1 and 15	23.50
Sterling registers, No. 8	30.00

Motors:

Westinghouse 12-A	$418
Westinghouse 38 and 38-B	562
Westinghouse 49	444
Westinghouse 68 and 68-C	483
Westinghouse 56	710
Westinghouse 93, 93-A and 93-A-2	735
Steel D	485
Steel type 29	485
Steel type 34	637

Controllers —

Westinghouse K- 6	$155
Westinghouse K-10	95
Westinghouse K-11	105
Westinghouse K-12	110
Westinghouse K-14	120
Westinghouse K-28	155
Westinghouse K-34-B	275
Steel D to replace with K-12 drums	32
Steel 34 to replace with K-12 drums	34
Steel D and steel 34, in first-class condition without replacement	75
Steel D and steel 34 replaced with K-12 drums	85

Automotoneers:

Style J and G	$ 12

Overhead Switches:

Westinghouse	$ 6.75
Steel	6.75

Circuit Breakers:

Westinghouse 44,884-B, 44,885-B, 44,886-B and 44,887-B	$ 25
Westinghouse 11,303-B, 11,304-B	45
General Electric form M. Q. with box	20

Grid Resistances:

Two grids, per set	$21.00
Three grids, per set	24.50
Four grids, per set	32.50
Five grids, per set	38.00
Two grids, per set strap	21.25

Car Fuses:

D. U. R.	$ 4.00
D. U. R. group 14	4.50

Lightning Arresters:

Average	$ 2.75

Choke Coils:

300 ampere .... $ 9.00

Car Wiring:

1 set cables —
50 ft. No. 1 cable
175 ft. No. 6 cable
200 ft. No. 4 cable
90 ft. of 2-in. cotton hose
Total .... $ 81.00

1 set cables —
50 ft. No. 1 cable
245 ft. No. 6 cable
385 ft. No. 4 cable
100 ft. of 2.5-in. cotton hose
Total .... $ 94.00

1 set cables —
50 ft. No. 1
300 ft. No. 6
185 ft. No. 4
100 ft. of 2-in. cotton hose
Total $105.00

1 set cables —
50 ft. No. 1
900 ft. No. 6
120 ft. of 2.5-in. cotton hose
Total $128.00

1 set cables —
50 ft. No. 2
450 ft. No. 4
325 ft. No. 6
150 ft. of 3-in. cotton hose
Total $151.00

Trolleys:

Harp, wheel, stand and pole $22.50

The following are costs of reproduction new of typical cars:

Group A: Jones 16 ft. closed car body, 26 ft. over all (seating capacity 21), single truck, double end, single door, cherry finish, veneer ceiling, carpet seats, Dupont truck.

Car body ($1,130 less $35 for carpet seats)	$1,095
Fittings and assembling:	
Double end storage air brake	205
Drop fenders, 2 at $30	60
Track scrapers, 2 at $15	30
Fare registers	20
Stove in box	25
Signs, hangers, racks, etc.	37
Handling, assembling, installing, including electrical work	152
Total car body	$1,624
Trucks, single, Dupont	350
Total car body and truck	$1,974
Motors, 2 steel D at $485	970
Controllers, 2 at $85	170
Automotoneers, 2 at $12	24
Overhead switches, 2 at $7	14
Grid resistances, 2	21
Car fuse, 1	4

Lightning arrester, 1	$ 3
Choke coil, 1	9
Car wiring and hose	105
Trolley	23
Total	$3,277

Group B: Lewis & Fowler 21 ft. closed car body (seating capacity 25), 32 ft. over all, single truck, single end, single door, cherry finish, carpet seats.

Car body	$1,332
Fittings and assembling	442
Trucks, storage air brake	191
Total body and trucks	$1,965
Electrical equip. (as in Group 1, deducting 1 controller, 1 auto and 1 overhead switch)	1,216
Total	$3,181

Group C: Cincinnati 23 ft. closed car body (seating capacity 30), 34¾ ft. over all, single truck, single end, single door, oak finish, hot air heaters, veneer ceiling, one register rod, cross-seats with stationary backs and spring rattan cushions, side aisle, Dupont trucks.

Car body	$1,442
Air heater	15
Fittings and assembling	442
Truck, single	350
Total body and trucks	$2,249
Motors, two 93-A at $735	1,470
Controller, 1 steel	85
Auto, 1	12
Westinghouse circuit breaker, 1	25
Grid resistances, 3	25
Car fuse, 1	4
Lightning arrester, 1	3
Choke coil, 1	9
Wiring and hose	105
Trolley	23
Grand total	$4,010

Group D: Cincinnati 29 ft. closed car body (seating capacity 40), 41 ft. over all, double truck, single end, double door, oak finish, veneer ceiling, spring rattan seats.

Car body	$2,125
Fittings and assembling:	
Single end storage air brake	183
Drop fender	30
Hot air heater	40
Signs	10
Hangers, racks, etc.	37
Fare register	29
Rear end snow scraper	18
One track scraper	15
Incandescent headlight	4
Lamps, resistance, switch bars, crushing bars, trolley rope, folder boxes, coal box, etc.	16

Handling, assembling, installing, incl. electrical work ($40) and material	$ 173
Total fittings and assembling	$ 555
Double trucks, standard 0-50	550
Total body and trucks	$3,230
Electrical equipment:	
Motors, 2 Westinghouse (93-A-2), at $735	$1,470
Controller, one K-12	110
Auto, 1	12
Circuit breaker, 1 Westinghouse	25
Grids, 2	21
Lightning arrester, 1	3
Choke coil, 1	9
Wiring and hose	94
Trolley	23
Total	$4,997

Group E: Stephenson 10 bench open car (seating capacity 50), 25 ft. body, 32½ ft. over all, single truck, single end, painted interior, painted slat seats with spindle backs, bronze trimmings, duck curtains, Dupont trucks.

Car body	$1,132
Fittings and assembling:	
Fender	30
Fare register backs	7
Signs, hanger and racks	5
Handling, assembling, installing, incl. electrical work	109
Total fittings and assembling	$ 153
Trucks	350
Total body, fittings and truck	$1,635
Electric Equipment:	
Motors, 2 steel D at $485	970
Controller, 1 steel	75
Auto, 1	12
Overhead switch, 1	7
Resistances, 2 strap	21
Car fuse, 1	4
Lightning arrester, 1	3
Choke coil, 1	9
Wiring and hose	94
Trolley	23
Grand total	$2,853

Group F: Stephenson 14 bench open car (seating capacity 70), 34 ft. body, 42 ft. over all, double truck, single end, St. Louis No. 47 and Brill 27-F truck, 4 Westinghouse 12-A motors.

Car body	$1,490
Fittings and assembling	373
Trucks	558
Total body, fittings and trucks	$2,421
Electrical equipment	2,052
Grand total	$4,473

Summarizing the cost of reproduction new of the revenue cars, we have:

Car bodies, fittings and trucks:

518 closed single truck cars	$1,095,603
230 closed double truck cars	745,705
230 open single truck cars	374,569
20 open double truck cars	48,420
3 miscel. revenue cars	14,046
1,001 car bodies, etc.	$2,278,343
Electrical equipment for same	1,186,427
Grand total, 1,001 cars complete	$3,464,770

The average cost of reproductiong new of each car was:

Car body, fittings and truck	$2,278
Electrical Equipment:	
Motors	977
Controllers	39
Automatoneer	8
Overhead switches	4
Resistance grids	22
Circuit breakers	11
Car fuse boxes	3
Lightning arrester	3
Choke coil	9
Car wiring	90
Trolley stand	21
Total electrical equipment	$1,187
Grand total	$3,465

The depreciated or present value of these revenue cars is:

Car bodies, fittings and trucks:

518 closed single truck cars	$ 765,768
230 closed double truck cars	662,071
230 open single truck cars	188,800
20 open double truck cars	43,234
3 miscel. revenue cars	13,456
1,001 car bodies, etc.	$1,673,329
Electric equipment	998,747
Grand total	$2,672,076

It will be noted that this depreciated value is 77.1% of the cost of reproduction new. An idea of the age of the cars may be gained from the following tabulation:

Closed single truck cars (518):

	Year purchased
99 in.	1895
339 prior to	1900
12 in.	1905
68 in.	1906
518	

Closed double truck cars (230):

60 in.	1903
46 in.	1904

49	in.	1905
50	in.	1907
25	in.	1908
230		

Open single truck cars (230):

230 prior to 1900

There are 104 non-revenue work or service cars and 2 non-revenue special cars whose cost of reproduction new is as follows:

Car bodies, fittings and trucks:

104 work cars	$ 97,692
2 special cars	3,703
Total car bodies, etc.	$101,395
Electrical equipment	95,808
Total	$197,203

The depreciated value is:

Car bodies, fittings and trucks	$100,670
Electrical equipment	74,532
Total	$175,202

This is 88.8% of the cost of reproduction new.

The work car equipment comprised the following:

		Cost of each
22	snow plows	$2,300 to $5,550
1	sprinkler (3,700 gals.)	2,733
2	wreckers	2,925
3	derrick cars	3,028
3	air compressor cars	2,000 to 3,224
8	locomotives, electric	2,000 to 2,300
1	concrete breaker (pile driver)	2,091
2	concrete mixer cars	3,755 to 7,596
12	ballast dump cars	900
26	flat cars, elec. ry.	450 to 700
16	flat cars, steam ry.	700 to 800
2	dry sand cars	800 to 2,770
1	rail grinder car	3,470
5	miscel. cars.	
104	total.	

The grand total cost of reproduction of the 1,001 revenue cars and the 104 work cars and 2 specials is $3,676,098; and the depreciated value is $2,861,403.

8. *Shops* — The valuation of the shop buildings has already been given under Buildings. There are two car shops whose cost of reproduction is as follows:

Monroe Shops:

Machinery and tools	$ 93,464
Patterns	4,737
Furniture and fixtures	11,586
Total	$109,787
Stock	121,688
Total Monroe Shops	$231,475

Harper Shops:

Machinery and tools	$ 24,591
Furniture and fixtures	405
Total	$ 24,996
Stock	4,189
Total Harper Shops	$ 29,185
Grand total both shops	$260,660

It should be noted that nearly half this amount is not shop machinery, but stock, and the amount of stock on hand appears to be excessive. A considerable part of the stock is scrap and second-hand material.

About $34,000 worth of patterns were not included in the appraisal. The report says: "Patterns are not an asset, as their cost is lost in the articles to which they are necessary as a matter of manufacturing. To have given the company the so-called cost of making patterns would have made it necessary to have eliminated the cost from the manufactured articles."

In the shops and at the various stations there are 14 air compressors having a total cost of reproduction of $18,552. There are 5 air charging plants having a total cost of reproduction of $2,931. The following is a fairly typical cost of reproduction of the air compressor outfits:

1 (9 ins. by 4½ ins. by 14 ins.) Hall Steam Pump Company's 2-stage water jacketed air compressor, capacity 125 cu. ft. free air at 125 r.p.m., operated with silent chain, not including Rochester automatic oil pump. This includes 50 h.p. Westinghouse motor and starter, automatic	$2,000.00
1 (9 ins. by 4½ ins. by 14 ins.) Hall Steam Pump Company's 2-stage water jacketed air compressor, capacity 125 cu. ft. free air at 125 r.p.m. operated with belt	1,050.00
1 75 h.p., type 75, series wound, Walker motor	500.00
2 Steel D controllers for hand starting, at $75	150.00
3 (3-ft. diam. by 15 ft. by 7-16 ins.) steel air storage tanks, lap jointed and double riveted, at $190	570.00
2 air gages, at $3.90	7.80
1 Rochester automatic oil pump, lubricators, tubing, etc.	141.82
Pipe, valves and fittings	118.31
Hose, shafting and charging boxes	152.39
Belting and pulleys	140.06
Lumber	33.79
Foundations	84.00
Chain falls and track	45.46
Electric switch board and wiring	250.79
Tools	50.00
Furniture and fixtures	67.85
Labor	773.60
Total	$6,135.87

The cost of a typical air charging plant is as follows:

2 air tanks at $190	$380.00
1 air gage	5.40
Valves, pipe and fittings	46.90
Hose and fittings	30.65

Charging boxes	$ 12.50
Labor	136.70
Total	$612.15

The cost of reproduction of car inspectors' stock and outfits at the 11 car stations is:

Tools	$ 6,168.88
Furniture	2,829.65
Stock	39,826.24
Total	$48,824.77

Summarizing, the following is the cost of reproduction and present value:

	Cost Reprod.	Present Value
Monroe Shops	$231,475	$174.074
Harper Shops	29,185	24,578
Air compressors, etc.	81,483	71,298
Inspectors' outfits	48,425	38,769
Totals	$390,968	$308,719

9. *Tools, Materials, Supplies, Furniture, Etc.*— The cost of reproduction new is appraised as follows:

Emergency station outfit	$ 76,144
Car station furniture	30,736
Office furniture, etc.	14,137
Total	$121,017
Stock for shop	237,541
Stock for track dept.	357,980
Stationary	34,478
Grand total	$751,016

The present value is estimated at $728,158.

The items of stock and stationary were inserted as given by the railway company, and the report states that the items were not checked by the appraisers as it was impossible at the time to distinguish what part of the stock was needed for the city lines and what for the interurban lines. The sub-committee on appraisal recommends a reduction of about $600,000 in this item.

In the fore part of this article it has been shown that this item 9, "Tools, materials, supplies, etc.," amounts to $4,407 per mile of trackway, which clearly shows that it includes a great amount of stock not needed for ordinary operation.

Another Appraisal of Detroit Street Railways. The following is abstracted from the Electric Railway Journal, May 17, 1913. In connection with a suit against a 3 ct. fare ordinance, the following appraisal data were submitted by Robert B. Rifenberick, consulting engineer of the Detroit United Railway Co. The costs relate only to the city lines of the company. The cost of reproduction was estimated to be:

(1)	Power department, labor and materials	$ 3,257,558
(2)	Track department, labor and materials	8,447,980
(3)	Mechanical department, labor and materials	5,051,781
(4)	General department, labor and materials	1,906,216
(5)	Total labor and materials	$18,663,536
(6)	Contingencies, 10%	1,050,294
(7)	Contractor's profit, 10%	1,148,777
(8)	Liability insurance, 2½% of wages	114,264
(9)	Builder's risk, 1½ to 2% of wages	17,243
(10)	Architects' fees, 5%	62,551
(11)	Cost of acquiring land, 10%	79,463
(12)	Engineering, 4%	720,955
(13)	Organization and administration, 5%	1,092,122
(14)	Carrying charges (interest), 9%	2,064,111
(15)	Financing, 8%	1,999,894
	Total	$27,013,210

The prices were those of Mar. 1, 1909, excepting for copper and cement which were averages of the preceding five years.

The following was a typical estimate of the cost of labor and materials in a mile of straight track.

DETAIL OF TRACK VALUATION, STRAIGHT TRACK CONSTRUCTION

Specification for 1 Mile of 7-in. 91-lb. Plain Girder Rail on Oak Ties in Ashphalt-Paved Street; 8-in. Concrete Construction

47,520	sq. ft. of 3½-in. asphalt top course and binder removed and hauled to dump, at 3 1-6 cts.	$ 1,504.80
829	cu. yd. of paving concrete removed and hauled to dump, at $5.21	4,319.09
1,515	cu. yd. of earth and sand excavation, at 35 ct.	530.05
1,515	cu. yd. of excavation removed to dump, at $1.43	2,166.45
1,222	cu. yd. of 8-in. concrete for track foundation, at $7.13	8,712.86
29	cu. yd. of sand cushion for tamping, lining and surfacing ties, at $2.01½	58.43
1,672	6-in. by 10-in. by 6-ft. 8-in. white oak ties laid 19 to 60 ft. rail length, at $1.18	1,972.96
143	tons of 7-in. 91-lb. plain girder open-hearth rail, in 60-ft. lengths, joints laid even and suspended between ties, at $43.44	6,211.92
19¾	kegs 9/16-in. by 5½-in. standard railroad spikes, at $5.05½	99.84
880	¾-in. by 5-ft. 2-in. round tie rods, ten to rail, with 4¾-in. nuts per rod, at 39½ cts.	347.60
1	mile of track laying	1,400.00
176	7-in. cast welded joints, at $4.25	748.00
10,560	lin. ft. of rail plastering, at 4½ ct.	475.20
715	cu. yd. of paving concrete laid, at $7.13	5,097.95
138	cu. yd. of sand cushion for paving, at $2.01½	278.07
4,974	sq. yd. brick paving, at $1.38½	6,888.99
306	sq. yd. of 3½-in. asphalt top and binder laid at $1.50	459.00
	Total cost per mile	$41,271.41
	Of this total the labor cost per mile is	20,063.29

Location of this construction, Jefferson Avenue from Bates Street to Mount Elliott Avenue, 20,740 lin. ft., 3,928 miles.

NOTE.— These are reproduction values as of March 1, 1909, and are based on hand labor and team haul, the average haul being 3 miles, and the assumption being that a team will average 2 tons per load and travel 18 miles per day.

Cost of Overhead-Trolley Systems. A. D. Williams, Jr., Engineering News, Dec. 23, 1909, gives the following cost data, obtained in the construction of a short interurban line in the northwestern portion of Ohio, running along country highways. The work was done in the summer time, and there were very few interruptions from the weather. The data are arranged, in all cases, to show costs per mile of a double-track road.

COST PER MILE (DOUBLE TRACK) OF OVERHEAD MATERIALS

4,254	lb. (2 miles) No. 00 trolley wire	at	$0.175	$754.45
104	trolley ears, No. 00, 15 in. long	at	0.23	23.92
104	cap and cone hangers, nut lock	at	0.30	31.20
500	ft. 5/16 in. galv. strand wire	at	0.012	6.00
500	ft. ¼ in. galv. strand wire	at	0.009	4.50
10	feeder clips	at	0.09	0.90
8	anchor ears	at	0.38	3.04
8	Lieb strain insulators, anchor	at	0.11	0.88
4	bridle clamps	at	0.19	0.76
2	Garton lightning arresters	at	3.10	6.20
8	wood screws	at	0.005	0.04
1	lb. friction tape	at	0.32	0.32
2	pins, bond of arresters to track	at	0.02	0.04
20	lb. 0 ground wire	at	0.06	1.20
20	lb. No. 0 copper strand insul. wire	at	0.18	3.60
25	galv. iron staples			0.05
2	trolley wire splicing sleeves	at	0.65	1.30
6	lb. solder ½ and ½	at	0.24	1.44
1	Brooklyn strain insulator	at	0.96	0.96
	Total cost of overhead material			$840.80

BRACKET-ARM CONSTRUCTION

With 37-ft. Poles Placed in Center.

Material:				
	Total cost overhead line material			$840.80
52	pine octagon poles, 12 in. by 8 in. by 37 ft.	at	$8.75	455.00
35	gal. graphite paint	at	1.15	40.25
4	cu. yd. concrete (1-3-5)	at	7.50	30.00
104	bracket arms complete	at	3.60	374.40
52	mach. bolts, 13 by ⅝-in. nut, washer	at	0.06	3.12
104	lag screws, ⅝-in. by 4-in.	at	0.025	2.60
104	lag screws, ⅝-in. by 3½-in.	at	0.025	2.60
400	ft. 5/16-in. galv. strand wire	at	0.012	4.80
10	feeder clamps	at	0.18	1.80
5	porcelain feeder insulators	at	0.04	0.20
5	galv. lag screws, ½-in. by 4-in.	at	0.02	0.10
12	drop forged eye-bolts, ⅝-in by 16-in.	at	0.09	1.08
7	gal. black paint	at	0.75	5.25
5	guy anchors	at	1.30	6.50
	Total materials			$1,768.50
Labor:				
52	poles, hauled and erected	at	$2.65	$137.80
52	poles, painting	at	0.30	15.60
	Erecting 2 miles of trolley wire	at	35.00	70.00
	Erecting bracket arms			30.00
	Hauling material			18.00
	Clearing foreign wires and poles			93.40
	Trimming trees			2.75
	Total labor			$367.55

Total materials per mile	$1,768.50	
Total labor per mile	367.55	
Total cost per mile of bracket-arm construction (with 37-ft. poles)	$2,136.05	

WITH 30-FT. POLES PLACED IN CENTER

Cost of 37-ft. pole construction		$2,136.05
Cost of 37-ft. poles, each	$8.75	
Cost of 30-ft. poles, each	5.75	
Difference on 52 poles at	$3.00	156.00
Total cost per mile of bracket-arm construction (with 30-ft. poles)		$1,980.05

CROSS-SPAN CONSTRUCTION

With 37 and 30-ft. Poles.

Material:

	Total cost overhead line material		$840.80
52	pine octagon poles, 12 in. by 8 in. by 37 ft. at	$8.75	455.00
52	pine octagon poles, 10 in. by 8 in. by 30 ft. at	5.75	299.00
8	cu. yd. concrete (1-3-5) at	7.50	60.00
2,300	ft. 5/16 in. galv. strand wire at	0.012	27.60
116	eye-bolts, ⅝-in. by 16-in. at	0.09	10.44
70	gal. graphite paint at	1.15	80.50
14	gal. black paint at	0.75	10.50
5	guy anchors at	1.30	6.50
400	ft. 5/16-in. galv. strand wire	0.012	4.80
	Total materials		$1,795.14

Labor:

104	poles, hauled and erected at	$2.65	$275.60
104	poles, painting	0.30	31.20
52	span wires, erected at	1.50	78.00
	Erecting 2 miles of trolley wire at	35.00	70.00
	Hauling materials		18.00
	Clearing foreign wires and poles		138.40
	Trimming trees		14.65
	Total labor		$625.85
	Total materials per mile	$1,795.14	
	Total labor per mile	625.85	
	Total cost per mile of cross-span construction (with 37 and 30-ft. poles)	$2,420.99	

WITH ALL 30-FT. POLES

Cost of 37 and 30-ft. pole construction		$2,420.99
Cost of 37-ft. poles, each	$8.75	
Cost of 30-ft. poles, each	5.75	
Difference on 52 poles at	$3.00	156.00
Total cost per mile of cross-span construction (with 30-ft. poles), dbl. track		$2,264.99

TRANSMISSION LINE

Provision was made for two lines of wires, but only one line was fully equipped.

Material, per mile:

52 cross arms, 4-in. by 5-in. by 6-ft., for two 2-in. pins	at	$0.39	$20.28
52 cross arms, 4-in. by 5-in. by 8-ft., for four 2-in. pins	at	0.53	27.56
312 2-in. locust pins	at	0.025	7.80
52 pairs gal. iron braces, 30-in. } 598 lb.	at	0.038	22.73
52 pairs gal. iron braces, 24-in. }			
208 carriage bolts, ⅜-in. by 4¾-in.	at	0.014	2.91
104 gal. iron lag screws, ½-in. by 4-ft.	at	0.018	1.87
208 gal. iron lag screws, ½-in. by 7-in.	at	0.025	5.20
156 6-in. porcelain insulators	at	0.46	71.76
2,100 lb. No. 4 bare copper wire	at	0.175	367.50
52 cable-top glass insulators	at	0.06	3.12
52 special locust pins	at	0.03	1.56
65 lb. No. 4 copper ground wire	at	0.175	11.38
3 No. 4 McIntire splices	at	0.15	0.45
7 gal. carbolized paint	at	0.65	4.55
900 lb. barbed wire, galv.	at	0.038	34.20
220 ft. ⅜-in. galv. strand wire ties	at	0.015	3.30
Total material for one mile			$586.17

Labor, per mile:

3 miles transmission line erected		$103.50
1 mile of ground wire erected		21.45
1 mile of barbed wire erected		21.45
Total materials per mile	$586.17	
Total labor per mile	146.40	
Total cost 1 mile of transmission line	$732.57	

FEEDER LINE

Material, per mile:

3,500 lb. 0000 feed wire	at	$0.075	$612.50
52 feeder pins	at	0.20	10.52
52 cable-top insulators	at	0.06	3.12
550 ft. 5/16-in. galv. strand wire	at	0.012	6.60
5 eye-bolts, ⅝-in by 16-in.	at	0.09	0.45
20 lb. No. 4 copper tie wire	at	0.175	3.50
2 lb. ½ and ½ solder	at	0.28	0.56
2 splices, 0000	at	0.22	0.44
Total for material			$637.69
Labor, erection of feeder wire			$45.00
Total material per mile		$637.69	
Total labor per mile		45.00	
Total feeder line per mile		$682.69	

COMPARISON OF COSTS, PER MILE, DOUBLE TRACK

	Bracket arm	Cross span 37 and 30-ft. poles	Cross span 30 and 30-ft. poles
Trolley wire and poles	$2,136.05	$2,420.99	$2,264.99
Transmission line	732.57	732.57	732.57
Feeder line	682.69	682.69	682.69
Total	$3,551.31	$3,836.25	$3,680.25

Overhead Line Construction. The following data, by E. P. Roberts and J. C. Gillette are from Engineering and Contracting, Dec. 11, 1907, taken from Electric Traction Weekly:

The following data on overhead line construction for interurban electric railways are based on actual practice and on the average costs of a large number of lines in different sections of the United States. The elements of interurban electric railway overhead line construction are: (1) A conductor from which the cars take electrical energy, and (2) the supporting of this conductor, which may be directly by brackets or by cross pans, which in turn are supported by poles. These two methods of construction are termed respectively bracket suspension and cross-suspension. The trolley wire may be supported either directly from insulators carried by the brackets or spans, or by steel cable, which in turn is supported by the brackets or spans. The former is the old and standard method of trolley construction so long used on direct current lines, while the latter is the new "catenary" type of construction. The work for a 600-volt direct current line will be considered first and then the work for a line for higher voltage alternating or direct current motors.

600-volt Direct Current Line. The general character of construction will be wooden poles with either bracket or cross suspension, probably the former, the poles being spaced 90 to 100 ft. For most interurban electric railways, even for light traffic, it is advisable to install two trolley wires, each of which is not less than No. 3/0 for heavy service, and in many cases No. 4/0 is preferable. In cases of very light traffic No. 2/0 may be advisable, as the necessity for reliability of service is lessened. In most cases there must be such amount of copper, either as trolley or as trolley and feeder wire, as will equal the cross section and weight of two No. 3/0 wires. It costs about as much to place such copper as feeder and trolley wire as it does if all is in the form of trolley wire, if the saving on siding construction is considered, and it is preferable to place two trolley wires, as this does away with overhead frogs, and in case of the breaking of a trolley wire avoids a tieup of the road. Trolley wire is hard drawn copper and is generally either figure 8 or grooved. Round wire is somewhat preferable for carshop yards and for sharp curves, such as turning corners on city streets, but the forms above stated are preferable for high speed runs because they give a smoother running surface.

The trolley wire is suspended from the bracket, or cross suspension, by means of a hanger, and such hangers are of several types. The hanger ear, or clip, which holds the trolley wire, should be of ample length, and for figure 8 or grooved wire, usually consists of two jaws clamped together by screws. The stud which supports such jaws passes into, and is supported by, the insulating material of the hanger, which insulating material is in turn supported by a cast iron or brass hanger body, which latter is secured to the bracket or to the cross suspension cable. In the past, troubles have been caused both by the mechanical weakness

of the structure, and also by the electrical weakness of the insulating material, especially after exposure to varying temperatures and climatic conditions, but hangers and clips of satisfactory design are now obtainable.

The trolley hanger may be supported by a bracket, or by a cross suspension cable. Steel cable should be not only of sufficient initial strength for the purpose, but also the galvanizing should be carefully inspected in order to assure long life. The bracket consists of steel tubing, angle iron or T-iron, generally painted in order to increase life, as well as to improve the appearance. An over support gives the maximum strength at least cost. In some cases an under support may be preferable, because of allowing less height of pole.

A telephone line is usually provided, and a metallic circuit is necessary. The wires are placed on cross arms or brackets, and with frequent transpositions. The wire for the telephone line is usually No. 10 B. & S. gage copper, if telephone line is more than 50 to 60 miles in length, but on shorter lines it may be high grade iron wire.

The costs submitted are probable costs between limits, but even though a maximum limit is given, the actual cost may sometimes exceed these figures, depending on local conditions.

Starting from the standpoint of the cheapest practicable construction, we have 30 ft. poles, 90 to 100 ft. spacing, and bracket supports, and with double overhead No. 000 trolley. The cost of such construction will approximate the figures given by Table IV.

TABLE IV. COST PER MILE OF BRACKET CONSTRUCTION SINGLE TRACK 600 VOLT TWO NO. 000 TROLLEY WIRES, POLES SPACED 100 FT.

	From	To
53 30-ft. poles in place and framed, poles delivered on cars $4.00–$6.00	$ 325	$ 475
53 brackets in place with fittings	180	210
Ears, hangers, etc., in place	50	75
2 miles No. 3/0 trolley with splicers, at 20 ct.–26 ct.	1,100	1,400
Erecting same	100	150
Siding construction pro rated	75	100
Curve construction 1,500 ft. additional cost	50	75
5 anchors	8.50	15
200 ft. strand for guys	2.25	2.50
2 half anchorages	5	10
Lags, clamps, etc.	5	8
Per cent. on material for handling	75	100
	$1,975.75	$2,620.50
Add for lightning arrester	10	20
Add for telephone system pro rated	75	100
	$2,060.75	$2,740.50
If all poles are anchored add	160	265
If 35-ft. poles are used add (poles $6.00 to $8.50)	130	160
Total	$2,350.75	$3,165.50

If for any reason it is decided to use suspension instead of bracket construction with the same pole spacing and size of trolley, then the approximate cost will be as given by Table V.

TABLE V. COST PER MILE OF SPAN CONSTRUCTION SINGLE TRACK 600 VOLT TWO NO. 000 TROLLEY WIRES, POLES SPACED 100 FT.

	From	To
106 30-ft. poles in place and framed, poles delivered on cars $4–$6	$ 650	$ 950
Ears, hangers, etc., in place	50	75
Span wire erected	60	85
2 miles No. 3/0 trolley at 20 ct.–26 ct.	1,100	1,400
Erecting same	100	150
Siding construction, pro rated	75	100
Curve construction, additional cost	35	60
5 anchors	8.50	15
200 ft. strand for anchor guys	2.25	2.50
2 half anchorages	5	10
Lags, champs, etc.	5	8
Per cent. on material for handling	100	150
	$2,190.75	$3,005.50
Lightning arresters	10	20
Telephone system pro rated	75	100
If all 35-ft. poles are used (poles at $6.00 to $8.50)	260	320
If poles are anchored add	320	530
Total	$2,856.75	$3,975.50

In case transmission wires are required for transmission of electric energy from the power house to substations, such transmission wires may be placed entirely on cross arms, or in the case of three phase transmission, two of such wires may be on one two-pin arm and the third wire on a pin on the top of the pole or on a bracket on the side of the pole. Of course the pole top cannot be used if a ground wire is located at such point. The cost of construction on a three-phase transmission line will approximate the figures given by Table VI.

TABLE VI. COST PER MILE OF BRACKET CONSTRUCTION SINGLE TRACK 600 VOLT TWO NO. 000 TROLLEY WIRES, POLES SPACED 100 FT. WITH THREE PHASE 33,000 VOLT TRANSMISSION LINE ON TROLLEY LINE POLES, 2-PIN CROSS-ARM AND POLE TOP PIN CONSTRUCTION.

	From	To
53 35-ft. poles in place and framed, poles delivered on cars at $6.00–$8.50	$ 455	$ 635
Ears, hangers, etc., in place	50	75
53 brackets in place with fittings	180	210
2 miles No. 3/0 trolley with splicer at 20 ct.-26 ct.	1,100	1,400
Erecting same	100	150
Siding construction pro rated	75	100
Curve construction 1,500 ft. additional cost	65	100
5 anchors	8.50	15
200 ft. strand for guys	2.25	2.50
2 half anchorages	5	10
Lags, clamps, etc.	5	8

		From	To
53	4 by 5 in. by 4 ft. 6 in. cross-arms........	$ 16	$22
159	2 by 13 in. oak pins paraffined	9	11
159	33,000 volt porcelain insulators..........	90	120
106	20 by 1¼ by ¼ in. cross-arm braces galv.	5	6.50
106	⅜ by 5 cge. bolts	1	1.25
53	½ by 4 lag bolts	0.60	0.75
53	⅝ by 13 mch. bolts	3	3.75
	Erecting arms, pins and insulators......	25	35
3	miles No. 2 copper wire with splicers at 20 ct.–26 ct.	638.40	829.92
	Erecting same	125	170
	Per cent. on material for handling........	140	190
	Total	$3,098.75	$4,095.67
	Add for trolley lightning protection	10	20
	Add for transmission lightning protection....	50	250
	Add for telephone system pro rated........	75	100
	Total	$3,233.75	$4,465.67
	If all poles are anchored add	160	265
	Total	$3,393.75	$4,730.67

From the above the principal unit costs of the cheapest practicable character of line work can be ascertained, and such additions must be made as are necessary for special overhead work around car shops, and in connection with bridges, city work or other special conditions; also the cost of copper for feeders or for transmission must be added in accordance with the plan decided upon.

The next consideration is as to whether or not there should be additional expenditures in order to increase reliability, or possibly to decrease maintenance or depreciation, or both. Some of the matters considered may be as follows: (1) Reduction of pole spacing; (2) increasing size of poles; (3) anchoring all poles.

Instead of using wooden poles the substitution for same of iron poles or possibly reinforced concrete poles, or, in extreme cases, which at present are not likely to be considered in connection with interurban electric railways, the use of steel bridges may be considered.

The matter of making stronger the supporting structure must necessarily be considered in connection with what it is to support, and frequently, also, in connection with the character of the ground.

Relative to the first, it is evident that the heavier the trolley wire the greater will be its strength, and therefore the greater the possible spacing of the supports, and also the greater the strength required at such supports. If catenary construction is used, usually the advisable spacing distance will be materially increased.

As to the second proposition, the less the first and maintenance cost per pole, then the nearer together the poles should be placed, but if the ground is rock, marsh, etc., it may be preferable to use structures allowing greater spacing and having increased unit cost, and possibly less cost per mile.

For standard trolley construction, the limit is usually 90 to 100 ft. spacing. These distances are determined, first, by the strains

in the trolley wire when it is pulled tight enough to give a steady running trolley wheel, not having too great a kink at the point where the trolley wire is supported from the bracket; and second, by the mechanical strength of the ear and the trolley wire where it is attached to the ear; consequently, if it is desired to increase the spacing of the supporting structures in order to reduce first cost and also maintenance charges, some form of support for the trolley wire other than the ordinary ears and hangers must be used.

Wooden pole construction for single or double track can be made amply strong up to a spacing of 150 ft. by using poles of commercial size, if same are properly set and proper consideration is given to the nature of the ground, the necessity of guying, etc. This refers to pole strength and not to the supporting of the wire.

The catenary supported trolley has been developed during the last two or three years. This method of suspension provides a safe means of supporting the trolley wire with spans up to 300 ft. in length. In this class of construction the trolley wire is suspended from a steel messenger wire supported by insulators carried on brackets, cross suspension cables or bridges. The trolley is supported from the messenger wire by hangers spaced from 10 to 50 ft. apart, depending upon the design. The physical limit of span in this class of construction is determined by the strength of the messenger cable, and also to a slight extent by the lateral movement of the trolley caused by wind pressure. It is evident that the tighter the messenger wire, the less will be the lateral movement in the trolley, but as the stresses in the messenger on spans of the same length and loading increase approximately inversely as the sag, care must be taken not to run above the safe loading of the messenger, especially under conditions of sleet and high wind.

There are two general classes of catenary construction, the single catenary, and the double catenary. In the single catenary construction the trolley wire is supported from a single steel cable carried by insulators upon the brackets or spans, while in the double catenary the trolley wire is carried by two steel cables.

In either type of construction the messenger cables may be carried either by brackets, span wires, or bridges. In ordinary interurban trolley construction, we usually find the messenger carried by a bracket, while in city streets we frequently find span wire construction. The bridge construction consisting of towers on each side of the track and a bridge spanning the tracks is seldom used for anything but the heaviest class of work, such as electrified steam railroads.

The bracket construction is the cheapest in nearly all cases, and is usually satisfactory for the purposes of the ordinary interurban road. The span wire construction is only used where conditions are such as to require it, as the span construction is rather expensive and not particularly satisfactory. It requires longer poles and produces a more severe loading of the poles than is the case with the bracket construction.

The double catenary construction produces a structure which is very rigid as regards wind pressure and yet is flexible as regards

vertical pressures. This type is the highest development of the art at this time, but because of its great cost is only used in the electrification of trunk lines of the heaviest class. It is not proposed in this article to discuss this phase of electric railroading, but to confine it to simpler and less expensive forms that are applicable to ordinary interurban roads.

As ordinarily constructed the single catenary trolley has a pole spacing of from 100 to 150 ft. and the trolley is attached to the messenger cable either by means of three hangers placed at intervals of 40 to 50 ft., or by means of nine or more hangers placed at intervals of 10 to 17 ft. The spacing referred to is, of course, the normal spacing and a larger or smaller number of hangers with longer or shorter spacing is used where local conditions require.

For convenience, we will hereinafter refer to the three hanger type of construction as the long spaced type, and that using nine or more suspension hangers as the short spaced type.

Messenger Cable.— In the single catenary construction the messenger or cable which supports the trolley consists of a steel cable ranging from perhaps 5-16 in., as a minimum, to ½-in. as a maximum, diameter, and usually made up of a seven wire strand, either of the grade known as "Siemens-Martin" steel or that designated "high strength steel." The cable is supported by porcelain insulators, such insulators being usually mounted on iron brackets. The following table gives the ultimate strength of the ordinary sizes of steel strand of the various grades:

Diam. in.	Reg.	Siemens-Martin	High Strength	Extra H.S.
¼	....	3,050	5,100	7,600
9–32	....	4,380	7,300	10,900
5-16	....	4,860	8,100	12,100
⅜	5,700	6,800	11,000	17,250
7–16	7,500	9,000	15,000	22,500
½	9,800	11,000	18,000	27,000
⅝	....	19,000	25,000	42,000

The prices of cable bear such relation to the strength that the cost of cable necessary to carry the given load is approximately independent of the grade of cable used. However, the lower grades of cable suffer most from corrosion, while the better grades are hardest to manipulate. It is practically impossible to "splice" the high strength or extra high strength steel cable, and all joints in such cables are made by means of clamps.

Brackets.— As there is considerable difficulty in keeping insulators in an upright position on pipe brackets, brackets are now generally made of 2¼ by 2¼ by ¼ or 5-16 in. T bar, or 2 by 2¼ by ¼-in. angle bars supported by a rod or strut. The insulators are attached to a suitable pin casting by means of Portland cement, such pin casting being held to the brackets by set screws.

Insulators.— The insulator is the vital point in high voltage trolley line construction, and as this insulator is subject to severe service, care should be taken in its selection. Insulators for 600 voltage work are generally 3 by 3½ ins., one piece, double petticoat por-

celain insulators, and tested for 5,000 volts. Of course with higher voltages, larger insulators are used; for example, with 6,600 volt current, insulators as large as 8 ins. in diam. by 5 ins. high are in use.

Hangers.— The hangers used to support the trolley from the messenger, in general consists of a mechanical clamp for the trolley, usually consisting of two sections drawn together by screws and resembling the so-called "Detroit" type of ear used in direct current practice. The attachment to the messenger is made by means of a clamp or metal loop, bolted around the messenger, or by means of a pair of sister hooks which are slipped over the messenger and driven down so as to tightly grip the wire. The connection between these two clamping ends is made by means of a round or a flat bar, or a pipe, attached to the above-mentioned parts by means of rivets, screws, or pipe threads.

All bolts and screws used in hanger construction should be thoroughly locked, as otherwise the vibration is certain to result in their working loose. The hanger should preferably expose as small an area as possible to wind at right angles to the trolley.

Catenary Construction on Curves.— On straight line construction and curve construction up to 5 deg., it is possible to maintain the 150 ft. pole spacing, but at 4 deg. and 5 deg. it is advisable to install a brail guy with two pull-offs per span. In installing pull-offs for catenary work, especially if pantograph trolley is to be used, great care must be taken to see that proper clearances are given for the end of the pantograph trolley, which on curve work will rise higher than the trolley wire itself, owing to the super-elevation of the rail at this point. The pull-off hangers, as they are called, for curve work are similar to the regular hangers except that they have an eye placed about 2 ins. above the trolley wire and another one about 2 ins. below the messenger. A short bridle is attached to these eyes and a strain insulator is cut in on the pull-off wire.

On curves up to 3 deg. the curves are held to position by means of steady braces, the brace being an insulated stiff rod attached to each bracket or pole and to the trolley wire in such manner as will resist any movement in a horizontal direction. There are several types in use at present. The earlier type consisted of a treated hickory rod attached to the pole by means of suitable clamps, and to the trolley wire by means of an ear similar to the regular hanger ear; this ear in turn being fastened to the rod by a gooseneck by means of a long threaded section for adjusting the position of the trolley wire. The more recent types are attached to the bracket arm, and do not depend upon the wooden rod for insulation but on porcelain insulators of the skirt type, similar in general construction to those supporting the messenger wire. There are two types in use, one having a long arm, which is attached to the bracket close to the pole, and the other having a short arm, which is attached to the outer extremity of the bracket; the arms in both cases being so hinged as to allow vertical but not horizontal motion.

It is advisable to install half anchorages at each end of curves of over 2 deg. in order to take care of the strains resulting from contraction in the line each side of the curve.

There is practically no tendency for the trolley to move sidewise, due to the passage of the trolley wheel or pantograph, as the messenger acts in effect like a large spring, and as soon as the trolley wheel or pantograph relieves it of some of the tension due to the weight of the trolley, the messenger will rise and thus keep directly over the trolley wire.

Sidings.— On siding construction, if the wheel trolley is used, the construction is similar to that used on high speed d. c. interurban roads; that is, the siding trolley is brought out to the main line at the switch, and then carried down the main line, parallel to and about 12 ins. distant from the main line trolley for a distance of 150 or 200 ft.

If the pantograph trolley is used, the deflector set, as it is called, consists of a number of trolley wires or steel rods of similar cross section. These are held to place by ordinary trolley ears, which in turn are bolted to cross bars spaced about 3 ft. apart, these cross bars being supported by the main line and siding trolley wires. The ends of these rods are raised 4 or 5 ins. above the siding and main line trolley so that there is no possible chance for the end of the pantographs to catch them. The siding trolley wire is passed over the top of the main line trolley wire and carried to an anchorage on the farther side. A deflector set should be installed on both sides of the main line trolley to avoid any danger of the pantograph catching trolley or guy wires. Care must be taken in this construction to see that the siding trolley is pulled up so that the raising of the main line trolley, owing to the passage of trolley wheel or pantograph, raises the siding trolley as well. It must also be designed so that the effects of lateral travel in the main line trolley, due to expansion and contraction, will not affect the height of the siding trolley.

A number of different types of section insulators are in use for this class of work. It is now recognized that the early forms, which depended on long breaks for insulation, are not practical. While at first they give fairly satisfactory results, climatic conditions soon produce leakage and make it unsafe to work on a section protected by such insulators. There are two or three different types of section insulators which have either a long air break or a series of short air breaks in their construction, and these give promise of proving satisfactory.

Overhead Crossings.— Probably the points which have given the most trouble to designers of catenary supported trolley work are those points on the line where the line is crossed by overhead bridges, used to eliminate grade crossings, as every foot these bridges are raised means an increased cost for the approaches and the structure, and the same is true if the clearance height between the bridge and track is increased by lowering the track grade. Consequently at these points the trolley is usually depressed to the lowest possible working limits.

Both the tension of the trolley and messenger and the upward pressure of the collecting device tend to lift these wires into contact with the bridge structure and they must be so secured as to resist these forces. In the case of ordinary d. c. construction, the trolley is rigidly supported by hangers closely spaced under the bridge, and the d. c. type of hanger is well adapted to resist such upward pressure. But with catenary construction the trolley and messenger must be flexibly supported and held securely against lateral and vertical motion, and this must be done in extremely limited space, and at the same time maintain clearances suitable for the voltages used. Catenary trolley construction requires approximately 18 ins. more clearance, or head room under bridge crossings than the ordinary d. c. trolley; this, of course, is based on trolley voltages of from 3,300 to 6,600 volts, where an air space of at least 5 ins. must be maintained between the messenger and trolley and the adjoining frame work of the bridge.

Two general types of bridge construction are in use, one known as the sleeve type and the other as the skirt type. The sleeve type consists essentially of a corrugated porcelain tube of proper length and thickness for the voltage used, which is supported on a bracket attached to the bridge; the messenger is tied to this, and the construction in other ways is similar to the ordinary bracket construction excepting that at this point a steady brace is installed which is anchored in such a manner as to prevent the trolley rising.

In the skirt type, the construction is similar to the ordinary bracket construction except that the insulator pin, instead of being supported by a bracket arm, is supported by either a wooden or steel bracket bolted to the bridge, and the messenger is suspended from a lien insulator as usual in bracket construction. In addition to this, extra hangers are placed between the two bridge supports in order to prevent the trolley wire rising at the center, because of the upward pressure of the pantograph or trolley wheel. On each side of the bridge at a distance of 20 to 25 ft., is placed what is called a "hold down span" consisting of two heavy poles securely anchored, with a cross span drawn tightly between them, the design of the span being such as to limit any rise of the trolley and messenger either because of contraction in the main line, or from lifting action of the trolley wheel.

With either construction the trolley and messenger wires must be protected from bridge drippings by means of a suitable metal shield attached to the bridge structure and thoroughly grounded. At points each side of the bridge where the trolley wire reaches its normal height half anchorages are installed in such manner as to pull slack towards the bridge.

Messenger Tension.— In erecting catenary trolley work care must be taken to see that the messenger wire is so pulled up that there will be exactly the same amount of deflection in spans of the same length. If this deflection is secured for the standard length spans, the shortened spans will take care of themselves, and the strains in all spans, due to loading, etc., will be the same. Unless the deflection is the same in spans of the same length the strains arising

from the loading of the trolley and also the vibration which is met in service will cause the messenger wire to "travel." This travel manifests itself by unequal strains on the messenger insulators and unless the tie is made very securely, the messenger wire will slip through and in this manner tend to equalize the tension, but the hangers will no longer stand vertically but will lay at an angle producing an uneven trolley surface, as well as an unsightly appearance of the whole construction. If the messenger wire does not slip through the tie, it will sooner or later twist the bracket around until the tension is equalized.

The strains in the messenger for any length of span and loading can be calculated by means of the following formula, which is expressed in simple arithmetic:

$S\,W$ = horizontal strain on wire at center of span.
S = strain coefficient.
W = weight per foot of span.

$$S = \frac{Y^2}{2X} + \frac{X}{6}$$

In which $Y = \frac{1}{2}$ the span in feet.
X = deflection at center of span in feet.

For example, with 150-ft. span of ⅜ in. messenger, weighing 45 lbs. and a deflection of 1.5 ft. we will have by substituting the values for the symbols:

$$S = \frac{(75)^2}{2 \times 1.5} + \frac{1.5}{6} = \frac{5625}{6} + \frac{1.5}{6} = 1875.25.$$

$W = 0.3.$
$S\,W = 0.3 \times 1875.25 = 562.575$ lb. strain at center of wire.

If this wire be used to support a trolley wire and hangers weighing 105 lbs. making the total weight supported by the messenger 150 lbs. or 1 lb. per ft. of span, we will have $S\,W = 1875.25$ lbs.

If the strains, due to sleet on the wire, are to be considered, the weight of the sleet is added to the weight per ft. of wire, and such sleet loading is usually taken as a layer of ice ½ in. thick, on all parts of the structure, the weight of ice being figured at 0.033 lb. per cu. in.

In determining the necessary strength of messenger, it is also usual to allow for the loading due to wind pressure, and this is commonly taken on wires or other cylindrical surface as 15 lbs. per sq. ft. of projected area, such area being taken at the increased figure due to ½ in. thickness of ice, and on flat surfaces at 27 lbs. per sq. ft. In order to obtain the strain on the messenger wire, due to wind pressure, we must calculate the area of the messenger wire, trolley, hangers, etc., which, multiplied by the pressure per square foot gives the strain due to wind.

The strain due to wind pressure does not add directly to that due to weight, but the total strain in the wire is proportional to the diagonal of a right triangle, of which the load due to weight forms one side, and the load due to wind forms the other side.

In deciding on the size of the messenger wire, it is necessary to

allow an ample factor of safety under the most severe conditions. The wire selected should be such as to give a factor of safety of not less than three under such conditions.

Care must be taken in the erection of the wire to allow for contraction of the wire in cold weather and the consequent flattening of the catenary which produces additional strains.

As a matter of fact the strains actually produced are usually materially less than those calculated because the entire structure is elastic and gives more or less, especially at the curves.

Costs.— Tables VII to IX show the average between limits of different types of catenary construction. Table VII shows the cost of single-track catenary 9 point suspension, 150 ft. pole spacing, bracket construction, and designed for 6,600 volt work. Table VIII shows cost of double-track catenary 9 point suspension, center pole construction, 150-ft. pole spacing for 6,600 volts. Table IX shows cost of double-track catenary 9 point double-pole bracket construction, 150-ft. spacing for 6,600 volts.

TABLE VII. COST PER MILE SINGLE-TRACK 9 POINT CATENARY 150-FT. POLE SPACING, 6,600 VOLT

	From	To
36 35-ft. poles in place and framed, poles taken at \$6 to \$8 delivered	\$ 310	\$ 430
36 brackets with fittings, in place	120	150
5,280 ft. No. 4/0 trolley, 3,382 lb. at 20 ct. to 26 ct. per lb.	676	879
5,300 ft. ⅜-in. high strength steel messenger cable	110	130
36 messenger insulators	15	30
36 spans catenary hangers	40	72
5 anchors	8.50	15
200 ft. ⅜-in. high strength strand for guys	2.25	2.50
10 steady braces for curves	30	40
10 strain insulators	11	15
Per cent. on material for handling, etc.	100	130
Labor erecting catenary trolley	160	200
Labor erecting curve trolley 1,500 ft. additional	50	75
2 half anchorages	20	30
Siding construction — pro rated	100	150
Lags, clamps, etc.	10	15
	\$1,762.75	\$2,363.50
Add for lightning arresters	10	60
Add for gd. wire ltg. protection	150	200
Add for telephone system — pro rated	100	150
	\$2,022.75	\$2,773.50
If all poles are anchored add	108	180
If brackets are insulated	40	60
Total	\$2,170.75	\$3,013.50

TABLE VIII. COST PER MILE OF DOUBLE-TRACK 9 POINT CATENARY, CENTER POLE, 150-FT. POLE SPACING, 6,600 VOLT

	From	To
36 35-ft. poles in place and framed, poles delivered on cars \$6 to \$8 each	\$ 310	\$ 430
72 brackets with fittings in place	240	300

	From	To
10,560 ft. trolley, 6,764 lb. at 20 ct. to 26 ct. per lb.	$1,352	$1,758
10,600 ft. ⅜-in. high strength steel messenger cable	220	260
72 messenger insulators	30	60
72 spans catenary hangers	80	144
10 anchors	17	30
300 ft. ⅜-in. strand for guy	3.50	4
20 steady braces for curves	60	80
20 strain insulators	22	30
10 30-ft. pull-off poles in place and framed	100	130
Per cent. for handling material, etc.	110	140
Labor erecting catenary trolley	320	400
Labor erecting curve trolley, 3,000 ft. add	100	150
2 half anchorages	40	60
Siding construction — pro rated	200	300
Lags, clamps, etc.	10	15
	$3,214.50	$4,291
Add for lightning arresters	10	120
Add for gd. wire lgt. protection	150	400
Add for telephone line	100	150
Total	$3,374.50	$4,961

TABLE IX. COST PER MILE OF DOUBLE TRACK 9 POINT CATENARY, DOUBLE POLE LINE, 150-FT. SPACING, 6,600 VOLT

	From	To
72 35-ft. poles in place and framed, poles at $6 to $8.50 each delivered on cars	$ 620	$ 860
72 brackets with fittings in place	240	300
10,560 ft. No. 4/0 trolley, 6,764 lb. at 20 ct. to 26 ct. per lb.	1,352	1,758
10,600 ft. ⅜-in. high strength steel messenger cable	220	260
72 messenger insulators	30	60
72 spans cat. hangers	80	144
10 anchors	17	30
300 ft. ⅜-in. strand for guy	3.50	4
20 steady braces for curves	60	80
20 strain insulators	22	33
Per cent. for handling material	130	160
Labor erecting 2 mi. catenary construction	320	400
Labor erecting 3,000 ft. curve construction add	100	150
2 double track half anchorages	40	60
Siding construction pro rated	200	300
Lags, clamps, etc.	10	20
	$3,444.50	$4,616
Add for lightning protection	20	240
Add for gd. wire lgt. protection	150	400
Add for telephone line	100	150
	$3,714.50	$5,406
If all poles are anchored	216	360
If all brackets are insulated	80	120
Total	$4,010.50	$5,886

In deciding whether the pole line for double-track shall be a double-pole line or a center-pole line, the character of the grading on the right-of-way will have to be taken into consideration. If,

as in the middle west, the country is practically level and no expensive cuts or fills are required, possibly the single-pole construction will show a saving over the double-pole; however, where there are expensive fills and cuts, the double-pole construction will show a saving over the single-pole, not in itself, but in the fact that the roadbed will not have to be as wide as for the single-pole construction.

Cost of Overhead Construction. The following costs, from Data, April, 1911, are averages on a road built in Illinois in 1909.

	Cost per mile
Poles, 35 ft., 55 at $6.45 each	$354.75
Poles, 30 ft., 55 at $4.20 each	231.00
Galv. strand, 5-16-in., 3,000 ft. at $0.87 per 100 ft.	26.10
Galv. strand, ¼-in., 2,000 ft. at $0.68 per 100 ft.	13.60
St. line hangers, 55 at $31.50 per 100 ft.	17.33
D curve hangers, 10 at $67.00 per 100 ft.	6.70
S curve hangers, 12 at $40.00 per 100 ft.	4.80
Wood strains, 9-in., 150 at $14.50 per 100 ft.	21.75
Strain plates, 2 at $32.00 per 100 ft.	0.64
Connectors, 20-in., 2 at $1.25 each	2.50
Ears (clip), 8-in., 55 at $14.00 per 100	7.70
Solder ears, 15-in., 25 at $32.00 per 100	8.00
Insulated crossings, 2 at $9.00 each	18.00
Solder, 25 lb. at $0.23 per lb.	5.75
Lightning arresters, 5 at $4.00 each	20.00
Feed-in yokes, 5 at $28.00 per 100	1.40
Section insulators, 1 at $5.60 each	5.60
Pony insulators, 190 at $1.51 per 100	2,87
Transposition insulators, 30 at $6.90 per 100	2.07
Wire, 3-0 trolley, 2700 lb. at $0.16 per lb.	432.00
Wire, 4-0 feeder, 3400 lb. at $0.16 per lb.	544.00
Wire, No. 10 tel., 2 mi. at $12.00 per mile	24.00
Wire, signal, 2 mi. at $15.30 per mile	30.60
Feeder insulators, 55 at $5.00 per 100	2.75
Pins, malleable iron, 5 at $16.20 per 100	0.81
Cross arms, 4 pin, 110 at $15.14 per 100	16.66
Locust pins, 440 at $13.80 per 1000	6.08
Eye bolts, ⅝- by 12-in., galv., 110 at $8.30 per 100	9.13
Eye bolts, ⅝- by 12-in. galv., 110 at $5.70 per 100	6.27
Lag screws, ½-by 4 in., 110 at $1.15 per 100	1.27
Braces, 24-in., galv., 220 at $53.00 per 1000	11.66
Bolts, carriage, ⅜- by 4-in., 220 at $6.50 per 1000	1.43
O washers, 2-in., 220 at $6.00 per 1000	1.32
Cut washers, ⅜-in., 220 at $0.85 per 1000	0.19
Switch pins, 3 at $4.00 each	12.00
Block signal, 1 at $250.00 each	250.00
Tools and incidentals	300.00
Labor, digging holes, 110 at $5.50 each	605.00
Labor, hauling, dressing and framing poles, 110 at $0.50 each	55.00
Labor, setting poles	110.00
Labor, line	300.00
Total	$3,470.73

Cost of Overhead Construction. We have taken the following from Pender's American Handbook for Electrical Engineers. The costs given in Tables X to XIII will serve as a guide in making preliminary estimates.

Extras for Curves.— Under ordinary conditions curves add about 10% to the cost of direct-suspension construction and about 15% to the cost of catenary construction.

Extras for 1200-volt construction.— The following amounts should be added to the total in the following table to give proper values for 1200-volt construction:

	Per mile
Direct suspension:	
Bracket construction	$40
Span construction	40
Catenary suspension:	
Bracket construction	$10
Span construction	10

TABLE X. COST PER MILE OF SPAN-WIRE TROLLEY CONSTRUCTION (600 VOLTS) (EXCLUSIVE OF TRACK WORK AND BONDING)

Item	Unit price	Single track Quantity	Single track Total cost	Double track Quantity	Double track Total cost
Material (incl. 2 double curves)					
Yellow pine poles, octagon	$6.00	88	$528	....	...
Iron poles, No. 2	19.00	....	....	88	$1672
Iron poles, No. 4	36.00	....	....	4	144
Cement	2.35 & 2.15	22 bbl.	52	33 bbl.	71
Broken stone	0.95	14 cu. yd.	13	14 cu. yd.	13
Black paint	0.90	20 gal.	18	11 gal.	10
Span wire	0.012	1250 ft.	15	2500 ft.	30
Pull-off wire	0.006	1250 ft.	8	2500 ft.	15
No. 000 cu. wire, per lb.	0.18	1 mi.	483	2 mi.	966
Straight line susp.	0.285	36	10	72	21
Side feed susp.	0.57	8	5	16	9
Deep groove ears	0.235	56	13	112	26
Frogs	3.25	2	7	4	13
Diagonals	3.60	..	..	2	7
Brooklyn strains	0.71	..	..	110	78
Frog pull-offs	0.36	6	2	12	4
Pole clamps	0.12	9	1	18	2
Globe strains	0.31	15	5	30	9
Side-feed wire, No. 0, ins.	0.102	120 ft.	12	240 ft.	24
Double bodies	0.93	6	6	12	11
Single "	0.53	6	3	12	6
Miscellaneous	...	..	1	..	7
Total mat'l.			$1182		$3138
Labor (incl. 2 double curves)					
Setting poles			$156		$138
Trucking			25		25
Painting (1 coat)			9		12
Running trolley wire			50		75
Building 2 double curves			34		50
Putting up span wire			20		20
Total labor			$294		$320
Grand total per mile			$1476		$3458

Cost of 11,000-volt catenary construction.— Under favorable conditions, an 11,000-volt catenary construction, such as that of the Denver & Interurban Ry., with sufficient conductors for a half-

hourly operation of two-car trains, including track bonding, costs from $3,500 to $5,000 per mile of single track. (O. S. Lyford, Proc. A. S. C. E., Aug., 1908, p. 540.)

For heavy catenary construction, such as used on trunk line railways, the cost depends entirely upon the standards selected, which are inclusive of the consideration of importance of track, in turn bringing into consideration the advisability of wood and steel post constructon, cross-catenary and bridge-span construction, single or compound catenaries, etc. The cost of overhead yard construction can vary from $1,500 to $3,000 a mile of single track, depending upon number of tracks spanned and type of construction selected.

TABLE XI. COST PER MILE OF SINGLE TRACK DIRECT SUSPENSION AND CATENARY CONSTRUCTION

Adapted from (G. E. Review, 1910, Vol. 13, p. 516)

600-VOLT LINE, TANGENT TRACK

Item	Direct suspension Bracket	Direct suspension Span	Catenary, three-point Bracket	Catenary, three-point Span
Material:				
Poles, 8 in. by 30 ft.	$265	$530	$180	$360
Anchor, guy and span cables	45	150	21	100
Messenger cable	..	..	92	92
No. 0000 trolley wire	540	540	540	540
Other line mat'l.	145	99	144	101
Total	995	1,319	977	1,193
Labor:				
Erecting poles	185	371	126	252
Mounting brackets	13	..	9	..
Installing span wire and guys	..	212	..	144
Stringing and clamping wire	75	75	200	200
Installing anchors	75	100	50	60
Total	373	758	385	656
Miscellaneous extras	150	150	150	150
Grand total	$1,518	$2,227	$1,512	$1,999

The following figures are representative of modern 11,000-volt trunk-line catenary construction, using steel bents similar to the recent construction on the N. Y. N. H. & H. R. R.

Number of tracks	Cost of construction per mile Of right of way	Cost of construction per mile Of single track
1	$ 4,000– 7,000	$4,000– 7,000
2	8,000–15,000	4,000– 7,500
4	25,000–40,000	6,250–10,000

Sidings, with wooden pole construction, cost from $2,500 to $3,500 per mile, and yard construction from $1,500 to $3,000 per mile of track.

Double Track Overhead Trolley Construction. The following is from a Chicago appraisal made in 1902, by. B. J. Arnold.

TABLE XII. ESTIMATED COST OF TRIANGULAR CATENARY CONSTRUCTION FOR 11,000-VOLTS, ORIGINAL N. Y. N. H. & H. TYPE

(Elec. Age, Apr., 1908, p. 96)

CONTACT LINE & SUPPORTS

Item	Quantity unit	Price	Per mile single track	Per mile four tracks
Steel bridges, intermediate, every 300 ft., wt. 13,000 lbs.	115 tons	$100.00	....	$11,500
Steel bridges, anchor; every 2 mi., wt. 23,000 lbs.	5¾ "	100.00	....	575
Foundations for intermediate bridge, 9 cu. yds. each side, 34 per mile	306 yds.	10.00	....	3,060
Foundations for anchor bridge, 12 cu. yds., 1 per mile	12 "	10.00	....	120
Foundations, special			....	775
Trolley wire, No. 0000 B. & S., 5280 ft.	3,380 lbs.	0.18	$608	
Messenger wires, 2-⅝ in. steel, 10,900 ft.	9,150 "	0.08	732	
Hangers, 10 ft. apart	528	0.75	395	
Insulators, two every 300 ft. ...	34	0.50	17	
Pins and yokes for above	34	0.75	26	
Strain insulator and accessories, 16 every two miles .	8	6.00	48	
Trolley strain insul. & section breaks, 4 every two miles .	2	16.00	32	
Circuit breakers, 8 per section ..	4	500.00	2,000	
Linemen's materials			20	
Labor on trolley, messenger and supports			1,200	20,308
Total for contact system			$5,078	$36,338

TABLE XIII. FEEDER SYSTEM

Item	Quantity unit	Price	Per mile four tracks
Feeder wires, No. 0 B. & S. (two) 10,900 ft.	3,380 lbs.	$ 0.18	$ 608
Insulators	35	0.50	18
Pins	35	0.50	17
Circuit breakers	1	500.00	500
Control wire and pipe	500 ft.	0.50	250
" transformers, 5 kw., 2 per section	1	100.00	100
Lightning arresters	..	....	50
Miscellaneous material	..	....	20
Labor on feeders	10,900 ft.	0.03	327
Total for feeder system			$1,890

ESTIMATE OF COST TO PRODUCE ONE MILE OF DOUBLE TRACK OVERHEAD TROLLEY CONSTRUCTION FOR CITY STREETS

100	Iron poles, set in concrete, at $28	$2,800.00
50	4-pin iron cross arms, with pins and ins., at $3.95 .	197.50
100	Small Brooklyn insulators for spans at 50 cts.	50.00
100	Globe strain " " " " 22 cts.	22.00

90 Straight line hangers at 32½ cts.	$ 29.25
10 Feed-in " " 50 cts.	5.00
140 Soldered 9-in. ears at 16 cts.	22.40
12 Live cross-overs (estimated) at $3	36.00
8 Insulated cross-overs (estimated) at $6	48.00
8 2-way frogs (estimated) at $3	24.00
3,000 ft. 5/16-in. galv. strand wire for spans at $10 per M	30.00
6 Strain plates (strain layout) at 32 cts.	1.92
12 Small Brooklyn (" ") " 50 cts.	6.00
12 Globe insulators (" ") " 22 cts.	2.64
1,500 ft. ¼-in. galv. strand wire (strain layout) at $7.25 per M.	10.88
20 Double hangers (2 double curve layouts) at 44 cts.	8.80
20 Single " (" " " ") " 35 cts.	7.00
1,000 ft. ¼-in. strand (" " " ") " $7.25 per M.	7.25
4 Heavy Brooklyn (2 double curve layouts) at 70 cts.	2.80
10,560 ft. 2-0 trolley wire, 4,246 lbs. at 13¼ cts.	562.59
2 00 splicing ears at 50 cts.	1.00
Labor, placing spans, trolleys, etc.	225.00
Total, exclusive of feeder wire	$4,100.03
Feeder wire, average per mile	4,000.00
	$8,100.03

Cost of Trolley Pole Line in Washington. The following actual costs are from a report by H. P. Gillette on his appraisal of an interurban traction company in Washington in 1912. Poles (cedar) were spaced 120 ft. apart on tangents and closer on curves. They were placed on one side of the track and 10 ft. from center line. They were of such length that the top of the pole was 37.5 ft. above the rail. They were framed for two cross arms, but the lower arm only was put on; it was a 6-pin arm 4 ins. by 5 ins. by 7 ft. The two pins at end of arm nearest track carry the #10 copper telephone wires. The feeder is carried on the first pin beyond pole from track. There were 637 poles (28,017 lin. ft.).

	Total	Per mile
Labor:		
Pay roll, construction (detail below)	$ 5,200.11	$437.02
Pay roll, other than construction crew	920.00	77.32
Total labor	$ 6,120.11	$514.34
Material:		
Poles (637)	$ 2,689.66	$226.04
Cross arms (750)	202.50	17.02
Pins (1,150)	65.09	5.47
Eye bolts	43.86	3.69
Cross arm braces	71.06	5.97
Machine bolts	250.60	21.06
Lag screws	38.70	3.25
Cut washers	69.47	5.84
Guy wire	52.39	4.40
Tools	0.85	0.07
Manilla rope	10.04	0.84
Freight and cartage	73.31	6.16
Personal expense	18.07	1.52
Blue prints	1.18	0.10
Temporary construction prorated	338.00	28.40
Total, material	$ 3,924.78	$329.83
Total, labor and material	$10,044.89	$844.17

Labor details follow:

		Total	Per pole
670 hrs.	foreman at $0.362	$ 240.24	$ 0.377
335 "	time-keeper at $0.272	91.16	0.143
904 "	framing poles at $0.260	234.75	0.369
5,811 "	digging holes at $0.258	1,500.86	2.356
1,802 "	putting on X-arms at $0.306	551.70	0.866
3,328 "	setting poles at $0.284	946.51	1.489
2,272 "	guying and anchoring at $0.289	655.90	1.030
475 "	putting on brackets at $0.305	144.85	0.228
53 "	blacksmithing at $0.301	15.95	0.025
1,038 "	making and hauling some of the poles at $0.292	303.55	0.477
136 "	miscellaneous hauling at $0.473	64.35	0.101
1,327 "	distributing poles at $0.287	380.34	0.597
254 "	" other material at $0.275	69.95	0.110
18,405 "	total at $0.232	$5,200.11	$ 8.168
	Pay roll other than construction	920.00	1.444
			$ 9.612
	637 poles purchased or cut, as below		4.220
			$13.832

Pole and fittings details:

545 main line poles	25,111 lin. ft.
24 brace-poles	690 " "
68 bridle poles	2,216 " "
637 poles, average 44 ft.	28,017 " "

Poles cut on right of way:

4,018 lin. ft. at 1¼ cts.	$ 50.20
9,070 " " at ¼ ct.	73.28
11,488 " " credit to r. of way at 7 cts.	804.16
1,657 " " at 2¼ cts.	41.42
3,150 " " at 3 cts.	94.50
Total right of way poles	$1,063.56

Poles purchased:

2,028 lin. ft. at 8 cts.	$ 162.24
146,386 " " at 10 cts	1,463.86
Grand total poles (637 poles) at $4.22	$2,689.66

Cross Arms:

750 6-pin at $0.27 .... $202.50

Pins:

300 1½ by 9 in. locust	$ 5.39
100 steel	14.70
750 No. 3 pins	45.00
Total pins	$ 65.09

Eye Bolts:

42 ⅞ in. by 7 ins. with 6 in. thread and nuts .... $ 43.86

Cross Arm Braces:

560 ¼ by 1¼ by 28 ins. galv.	$ 51.03
330 ¼ by 1¼ by 20 ins. "	20.03
Total cross arms	$ 71.06

Machine Bolts:

3,260 ⅜ by 5 ins. galv.	$ 57.37
400 ⅜ by 5 ins. black	5.63
444 ⅝ by 16 ins. galv.	36.01

1,250 ⅝ by 18 ins. galv.	$110.88
220 ⅝ by 18 ins. black	24.09
100 ⅝ by 22 ins. galv.	16.62
5,674 Total machine bolts	$250.60

Lag Screws:

1,730 ½ by 4 ins. galv.	$ 36.11
60 ½ by 5 ins. "	2.59
Total lag screws	$ 38.70

Cut Washers:

3,260 ⅜ in., 68 lbs.	$ 6.12
3,790 ⅝ in., 1,050 lbs.	63.35
Total cut washers, 1,118 lbs.	$ 69.47

Guy Wire:

4,000 ft. ⅜ in. single galv. strand, 1,195 lbs.	$ 52.39

Labor Costs on Trolley Line in Washington. The following data were prepared by Henry L. Gray for an appraisal on the Pacific Coast in 1912. An economical method of constructing a trolley system involves the use of one or more gangs made up as follows, per day of 8 hrs.

1 foreman at $5.00	$ 5.00
2 linemen at $4.40	8.80
1 helper at $2.75	2.75
1 auto truck with helper-driver at $1.25 per hr. for 8 hrs.	10.00
Total for 8-hr. day	$26.55
Average cost of crew per hr.	$ 3.32

On straight span construction this crew could average 2 spans per hour, at a labor cost of $1.66 per span. This figure covers the placing of pole collars on metal poles and the boring for eye bolts in wooden poles, but does not include the drilling, etc., for building contacts.

The locating of the frog and pullovers at the point where two tracks merge into one (end of double track) can be done by the above crew in approximately an hour, a labor cost of $3.35.

The adjustment of the 2 frogs, the 2 pullovers and the stringing of the wire at a standard crossover has been found by experience to be about 4 hrs., which gives a labor cost of $13.30.

The stringing of the guys and adjusting the alignment of a single track curve of 90 degs., would require approximately 8 hrs., a labor cost of $26.60.

The stringing of the guys and adjusting the alignment of a double track curve of 90 degs. would require approximately 12 hrs., a labor cost of $40.

The stringing of the guys and adjusting the alignment of a double track of 45 degs. would require approximately 10 hrs., a labor cost of $33.20.

The stringing of the guys, location of 3 frogs and alignment of the 2 curves of a single track wye would require approximately 12 hrs., a labor cost of $40.

The stringing of the guys, location and 3 frogs and 1 crossover, together with the alignment of the 2 curves of a wye located on a double track would require approximately 12 hrs., a labor cost of $40.

The stringing of the guys, location of 4 frogs, and a crossover with the adjusting of the alignment of the 3 curves of a double track branchoff from double track with a single track curve forming a wye, would require approximately 12 hrs., a labor cost of $40.

The stringing of the guys, location of 2 frogs and adjustment of the alignment of the 2 curves of a simple double track branchoff from the double track would require approximately 8 hrs., a labor cost of $26.60.

The stringing of the guys, the location of 12 frogs and 12 crossovers, and the extensive adjustments to maintain the alignments of all the curves in a layout comprising a double track crossing at 90 degs. with 3 pairs of connecting curves would require approximately 32 hrs., a labor cost of $106.25.

The stringing of the guys, the location of 8 frogs and 8 crossovers, and the adjustment of the alignment of the curves of a double track crossing at 90 degs. with 2 pairs of connecting curves located diagonally to each other, would require approximately 16 hrs., a labor cost of $53.20.

The stringing of the guys, the location of 6 frogs and 3 crossovers, and the adjustment of the alignment of the curves of a double track with 2 double track curves leading into a double track at 90 degs. would require approximately 16 hrs., a labor cost of $53.10.

In stringing trolley wire it would be economical to add an auto truck with driver, a lineman and 2 helpers to the standard crew, at an additional cost of $19.90 per day, based on the same rates. This would make the total crew cost $46.45 per day. It is estimated that this crew can hang up 1½ miles of trolley per day, the adjustment of alignment on curves and special layouts being covered in the cost of the layouts. This would make the average cost of stringing $31 per mile.

Overhead Trolley Construction in Chicago. The following data are abstracted from Detailed Exhibits of the Physical Property and Intangible Values of the South Chicago City Railway Co., and the Calumet-Electric Street Railway Co., as of February 1, 1908, accompanying the Valuation Report by B. J. Arnold and George Weston.

TABLE XIV. UNIT POLE COSTS

WOOD POLES, CEDAR

Length, ft., and diam. top, ins.	30–7	35–7	40–8	45–8	50–8	50–8
Pole	$5.20	$8.10	$11.45	$15.10	$15.40	$17.60
Labor	2.80	2.90	3.05	3.25	3.60	4.00
Total cost,						
Heeled and breasted	8.75	11.75	15.20	19.10	19.75	22.35
Set in barrels	9.50	12.00	15.50	19.35	20.00	22.60
Set in rock	10.00	13.00	16.50	20.35	21.00	23.60
Set in 1 yd. concrete	11.50	14.50	18.00	21.85	22.50	25.10
With S. P. brace	9.00	12.50	16.00	19.85	20.50	22.10

The scrap value of each of the above was estimated to be $1.00.

IRON POLES

Length, ft.	25	30	30	30	35	35
Size, in.	4-5-6	4-5-6	5-6-7	6-7-8	5-6-7	6-7-8
Weight, lb.	450	525	1100	1322	1220	1479
Cost, pole only,* dol.	15.75	18.37	38.50	46.27	42.70	51.76
Cost, set in 1 yd. concrete, dol.	22.37	25.18	46.75	55.00	51.25	61.00
Scrap value, dol.	1.69	1.97	4.15	4.95	4.55	5.55

* Based upon a price of $0.035 per lb.

WOOD POLE CROSS SPAN CONSTRUCTION

1 TROLLEY, 1 TRACK

2 ⅝-in. by 12-in. eye bolts	$0.24
48 ft. span wire	0.55
2 wood strain insulators	0.40
1 Ohio brass, or equal, hanger	0.45
1 trolley ear, 12-in.*	0.35
Labor	2.00
	$3.99

* For 15-in. ears add $0.20 for each ear to prices given.

1 TROLLEY, 1 TRACK, FEED SPAN

2 ⅝-in. by 12-in. eye bolts	$0.24
36 ft. No. 1/0 solid copper wire	1.47
19 ft. span wire	0.21
2 wood strain insulators	0.40
2 trolley ears, feeder	0.70
1 stud bolt	0.15
Labor	2.00
	$5.17
Scrap value	$1.25

2 TROLLEYS, 2 TRACKS

The cost of this will be the same as that of 1 trolley, 1 track, plus 1 hanger, $0.45, and 1 ear, $0.35, a total of $4.79. If no wood strains or only one wood strain is used the costs will be $4.39 and $4.59 respectively. If 2 Anderson solid hangers, $0.76, are used instead of O. B. hangers the cost is $4.65, instead of $4.79.

2 TROLLEYS, 2 TRACKS, FEED SPAN

The cost of this is $5.87, being that of 1 trolley, 1 track, feed span, $5.17, plus 2 trolley ears, $0.70. The scrap value is $1.45.

Another type is as follows:

2 ⅝-in. by 12-in. eye bolts	$0.24
48 ft. span wire	0.55
51 ft. No. 1/0 solid copper wire	2.65
2 O. B., or equal, hangers	0.90
2 trolley feed ears	0.70
2 wood strains	0.40
Labor	2.00
	$7.44
Scrap value	$1.75

4 TROLLEYS, 2 TRACKS

2 ⅝-in. by 12-in. eye bolts	$0.24
82 ft. span wire	0.92
3 wood strains	0.60
4 O. B., or equal, hangers	1.80
4 ears, 12-in.	1.40
Labor	2.00
	$6.96

IRON POLE CROSS SPAN CONSTRUCTION

2 TROLLEYS, 2 TRACKS

2 pole collars	$0.18
2 globe strain insulators	0.60
48 ft. span wire	0.55
2 wood strain insulators	0.40
2 O. B., or equal, hangers	0.90
2 trolley ears, 12-in.	0.70
Labor	2.50
	$5.83

3 TROLLEYS, 3 TRACKS

2 pole collars	$0.18
6 globe strains	1.80
48 ft. span wire	0.55
3 O. B., or equal, hangers	1.35
3 trolley ears, 12-in.	1.05
Labor	2.50
	$7.43

IRON CENTER POLE CONSTRUCTION

4 TROLLEYS, 2 TRACKS

1 O. B. bracket for iron poles, type "D"	$ 7.92
4 Anderson solid hangers	1.52
4 trolley ears, 12-in.	1.40
Labor	4.00
	$14.84

4 TROLLEYS, 2 TRACKS, FEED TAP

In addition to the above the feeder tap has 18 ft. No. 1/0 copper wire R. C., $1.41, and 5 ft. 1 in. loons, $0.50, making a total of $16.75. The scrap value is $1.00.

Labor Cost of Overhead Trolley Work. The unit costs of rebuilding a trolley line 7.68 miles long in Washington follows:

Distributing 401 poles, each	$0.70
Digging 401 holes, each	4.00
Shaving 25 poles, each	1.16
Setting and tamping 401 poles, each	2.70
Framing 401 poles, each	0.70
Double arming and bracing, 7.68 miles, per mile	55.04
Guying, 7.68 miles, per mile	21.75
Distributing material, 7.68 miles, per mile	8.35
Putting up 95 spans, each	1.25
Trolley work, 9.5 miles, per mile	91.90
Putting up 115,000 ft. feeders, per ft.	0.0057
Taking down old trolleys, 9.5 miles, per mile	8.88

The wages of linemen were 30 cts. per hour; and of helpers, 25 cts. per hour.

The following actual labor costs are for 4.12 miles of new trolley line work, totaling $3,188 or $775 per mile, including $212 per mi. for trainmen:

Digging 215 holes, each	$ 1.04
Raising 215 poles, each	1.39
Framing 215 poles, each	0.93
Hauling 215 poles, incl. loading and distributing, each	0.60
Guying and bracing 75 poles, each	3.98
Stringing 4.12 miles of trolley, incl. building curves, per mile	108.00
Putting up 180 brackets, each	0.54
Miscellaneous, 4.12 miles	33.61
Telephone and telegraph, 12.36 miles of wire, per mile	14.20
Stringing feeder, 4.12 miles, per mile	63.50

The cost of setting 57 35-ft. trolley poles, same place, was as follows, per pole:

Digging holes	$1.49
Raising poles	1.25
Framing poles	0.97
Hauling poles	0.49
Miscellaneous labor	0.30
Total per pole	$4.50

The cost of putting up 48 trolley wire spans was $1.45 each.

Valuation of Distribution System of the Chicago Consolidated Traction Co. From an article by P. J. Kealy, Engineering and Contracting, Oct. 5, 1910.

The electric power distribution system has been divided into: Overhead Trolley Construction; Feeder System; Electrical Track Bonding; Conduit System.

The report on the valuation by B. J. Arnold includes a detailed estimate of all poles, cross span construction, fittings, trolley wire, feeder wire (positive and negative), feeder attachments and supports, track bonding cable, wire, etc., together with special work construction at the curves and in car houses.

In arriving at the cost new of the poles, wire attachments, and all equipment whatsoever, the actual cost of the material and labor was estimated at the present time (Nov. 1, 1909), and to this was added 15% for organization, engineering, and incidentals. The detailed inventory of the entire system was made by inspection, and all quantities, kinds, conditions, and character whatsoever were fully noted in detail, from which the cost has been estimated.

Overhead Trolleys.— There are 129.623 miles of overhead trolley construction, the valuation of which is summarized as follows:

	Cost new
Owned by companies	$207,339
Outside interests	8,460
Net total	$198,879
Org., eng. and inc., 15%	29,832
Grand total	$228,711
Per mile	1,759

The unit costs used in figuring transmission line values are shown by Tables XV, XVI, XVII and XVIII.

TABLE XV. TROLLEY AND FEEDER COST DATA

Kind	Size.	Weight in lb. per 1,000 ft.	Material per ft.	Labor per ft.	Total cost per ft.
Trolley	1/0 New	319.5	$0.047	$0.01	$0.057
Trolley	1/0 (18/64 scrap)	239.0	0.027	...	....
Trolley	2/0 New	402.8	0.059	0.01	0.069
Trolley	2/0 (20/64 scrap)	296.0	0.033	...	....
W. P.	2/0	522	0.077	0.01	0.087
Scrap	2/0	410	0.045	...	....
W. P.	4/0	800	0.118	0.01	0.128
Scrap	4/0	653	0.073	...	....
W. P.	350 M. cir. mils.	1,345	0.202	0.015	0.217
Scrap	350 M. cir. mils.	1,076	0.119	...	....
W. P.	500 M. cir. mils.	1,894	0.284	0.015	0.299
Scrap	500 M. cir. mils.	1,540	0.171	...	....
W. P.	1,000 M. cir. mils.	3,674	0.551	0.04	0.591
Bare	1,000 M. cir. mils.	3,100	0.468	0.04	0.508
Scrap	1,000 M. cir. mils.	3,100	0.344	...	....
Lead .... Covered	350 M. cir. mils.	3,495	0.506	0.04	0.546
5/32 Rubber.... 1/8 Lead	500 M. cir. mils.	4,254	0.63	0.04	0.67

In arriving at the above prices, quotations of November 1, 1909, were used, namely:

Bar Copper at mill ....0.1325 per lb.
Solid Wire (either bare or weather proof) ....0.1460 per lb. f.o.b. Chicago
Stranded Bare Cable ....0.1510 per lb. f.o.b. Chicago
Stranded W. P. Cable ....0.1485 per lb. f.o.b. Chicago
Scrap Value (Copper Wire and bronze parts) ....0.11 per lb. f.o.b. Chicago

1% was added for sag.

TABLE XVI. POLE COSTS; IRON POLES

Size, in.	Length, ft.	Weight, lb.	Cost pole only	Set in street in concrete	Set inside curb in concrete
4-5-6	28	503	$14.83	$20.83	$25.45
4-5-6	30	532	15.63	21.63	26.25
5-6	30	546	16.02	22.02	26.64
5-6-7	30	675	19.55	25.55	30.17
5-6-7	31½	955	27.25	33.25	37.87
5-6-7	31	689	19.95	25.95	30.57
5-6-7	33	731	21.11	27.11	31.73
4-5-6-7	33	722	20.86	26.86	31.48
5-6-7	35	778	22.27	28.27	32.89
4-5-6-7	40	852	24.40	30.40	35.02
5-6-7-8	40	1,052	29.95	35.95	40.57
5-6-7	45	950	27.15	33.15	37.77
6-7-8	30	829	23.80	29.80	34.42
6-7-8	31	876	25.10	31.10	35.72

Size, in.	Length, ft.	Weight, lb.	Cost pole only	Set in street in concrete	Set inside curb in concrete
6-7-8	33	916	26.30	32.30	36.92
6-7-8	35	966	27.55	33.55	38.17
6-7-8	40	1,087	30.90	36.90	41.52
6-7-8-9	40	1,273	36.00	42.00	46.62
6-7-8	45	1,273	36.00	42.00	46.62
6-7-8-9	45	1,428	40.30	46.30	50.92
6-7-8-9	50	1,602	45.04	51.04	55.66
(Bracket Type complete.)					
3-4-5-6	30	913	31.00	41.62	....

TABLE XVII. POLE COSTS; WOOD POLES

Diam. of top, in.	Length, ft.	Cost of pole	Cost of setting (labor, material, cartage)	Total cost
6	20	$1.00	$2.80	$3.80
6	25	2.00	3.50	5.50
6 Special	30	1.95	3.95	5.90
7	30	4.45	4.05	8.50
8	30	6.10	4.05	10.15
6	35	4.45	4.05	8.50
7	35	6.10	4.05	10.15
8	35	7.30	4.20	11.50
6	40	6.13	4.20	10.33
7	40	7.30	4.20	11.50
8 Special	40	7.30	4.20	11.50
6	45	7.30	4.60	11.90
7	45	9.00	4.60	13.60
8	45	9.00	4.60	13.60
6	50	9.00	5.00	14.00
7	50	12.00	5.00	17.00
8	50	12.50	5.00	17.50
7	60	16.00	5.00	21.00
Stub	30	6.10	4.05	10.15
Stub	35	7.30	4.20	11.50

TABLE XVIII. UNIT COSTS OF SPAN CONSTRUCTION OF VARIOUS TYPES

A. Two Trolleys — Span Construction — Two Iron Poles.

	Total
2 Pole bands (solid 2-bolt), at $0.25	$0.50
2 Brooklyns (medium, malleable iron), at $0.60	1.20
2 Straight line hangers, W. E. Type A or equal, at $0.40	0.80
2 Ears, 12-in. clinch, at $0.25	0.50
45 Ft. 5/16-in. span wire, at $0.008	0.36
Labor	2.50
	$5.86
Incidentals and waste at 5%	0.29
Total	$6.15

B. Two Trolleys — Section Insulators — Span Construction — Two Iron Poles.

	Total
2 Pole bands (solid 2-bolt), at $0.25	$ 0.50
2 Brooklyns (mediums, malleable iron), at $0.60	1.20
2 Section insulators (Phila. type), at $4.50	9.00

45	Ft. 5/16-in. span wire, at $0.008	0.36
	Labor	2.50
		$13.56
	Incidentals and waste at 5%	0.68
	Total	$14.24

C. Two Trolleys — Feeder Span Construction — Two Iron Poles.

		Total
2	Pole bands (solid 2-bolt), at $0.25	$0.50
2	Brooklyns (medium, malleable iron), at $0.60	1.20
2	Wood strains, 1¼-in. by 9½-in., at $0.15	0.30
2	Solid feed hanger ears, at $0.45	0.90
30	Ft. 4/0 W. P. wire, at $0.118	3.54
15	Ft. 5/16-in. span wire, at $0.008	0.12
	Labor	2.50
		$9.06
	Incidentals and waste at 5%	.45
	Total	$9.51

D. Two Trolleys — Span Construction — One Wood and One Iron Pole.

		Total
1	Pole band (solid 2-bolt), at $0.25	$0.25
1	Brooklyn (medium, malleable iron), at $0.60	0.60
1	Steel eyebolt, 12-in., at $0.05	0.05
2	Straight line hangers, W. E. type A or equal, at $0.40	0.80
2	Ears, 12-in. clinch, at $0.25	0.50
40	Ft. 5/16-in. span wire, at $0.008	0.32
	Labor	2.50
		$5.02
	Incidentals and waste at 5%	.25
	Total	$5.27

E. Two Trolleys — Section Insulators — Span Construction — One Wood and One Iron Pole.

		Total
1	Pole band (solid 2-bolt), at $0.25	$ 0.25
1	Brooklyn (medium, malleable iron), at $0.60	0.60
1	Insulated eyebolt, at $0.16	0.16
1	Wood strain, 1¼-in. by 9½-in., at $0.15	0.15
2	Section insulators (Phila. Type), at $4.50	9.00
35	Ft. 4/0 W. P. wire, at $0.118	4.13
12	Ft. 5/16-in. span wire, at $0.008	0.10
	Labor	2.50
		$16.89
	Incidentals and waste at 5%	.84
	Total	$17.73

F. Two Trolleys — Feeder Span Construction — One Wood and One Iron Pole.

		Total
1	Pole band (solid 2-bolt), at $0.25	$0.25
2	Brooklyns (medium, malleable iron), at $0.60	1.20
2	Wood strains, 1¼-in., 9½-in., at $0.15	0.30
1	Insulated eyebolt, at $0.16	0.16
2	Solid feed hanger ears, at $0.45	0.90
30	Ft. 4/0 W. P. wire, at $0.118	3.54

12	Ft. 5/16-in. span wire, at $0.008	0.10
	Labor	2.50
		$8.95
	Incidentals and waste at 5%	0.45
	Total	$9.40

G. Two Trolleys — Span Construction — Two Wood Poles.

		Total
2	Insulated eyebolts, at $0.16	$0.32
2	Straight line hangers, W. E. type A or equal, at $0.40	0.80
2	Ears, 12-in. clinch, at $0.25	0.50
30	Ft. 5/16-in. span wire, at $0.008	0.24
	Labor	2.50
		$4.36
	Incidentals and waste at 5%	0.22
	Total	$4.58

H. Two Trolleys —-Feeder Span Construction — Two Wood Poles.

		Total
2	Insulated eyebolts at $0.16	$0.32
1	Globe strain, 2½-in. at $0.25	0.25
1	Wood strain, 1¼-in. by 9½-in., at $0.15	0.15
2	Solid feed hanger ears, at $0.45	0.90
30	Ft. 2/0 W. P. wire, at $0.77	2.31
20	Ft. 5/16-in. span wire, at $0.008	0.16
	Labor	2.50
		$6.59
	Incidentals and waste at 5%	0.33
	Total	$6.92

I. Two Trolley — Section Insulators — Span Construction — Two Poles.

		Total
2	Insulated eyebolts at $0.16	$ 0.32
1	Wood strain, 1¼ by 9½-in., at $0.15	0.15
2	Section insulators (Phila. type), at $4.50	9.00
45	Ft. 5/16-in. span wire, at $0.008	0.36
	Labor	2.50
		$12.33
	Incidentals and waste at 5%	0.62
	Total	$12.95

K. One Trolley — Span Construction — Two Iron Poles.

		Total
2	Pole bands (solid 2-bolt), at $0.25	$0.50
2	Brooklyns (medium, malleable iron), at $0.60	1.20
1	Straight line hanger, W. E. type A or equal, at $0.40	0.40
1	Ear, 12-in. clinch, at $0.25	0.25
40	Ft. 5/16-in. span wire, at $0.008	0.32
	Labor	2.00
	Labor	2.00
		$4.67
	Incidentals and waste at 5%	0.23
	Total	$4.90

N. One Trolley — Span Construction — One Iron and One Wood Pole.

1	Pole band (solid 2-bolt), at $0.25	$ 0.25
1	Brooklyn (medium, malleable iron), at $0.60	0.60
1	Insulated eyebolt at $0.16	0.16
1	Wood strain, 1¼ in. by 9½ in., at $0.15	0.15
1	Straight line hanger, W. E. type A or equal, at $0.40	0.40
1	Ear, 12 in. clinch, at $0.25	0.25
40	Ft. 5/16 in. span wire, at $0.008	0.32
	Labor	2.00
		$4.13
	Incidentals and waste at 5%	0.21
	Total	$4.34

O. One Trolley — Span Construction — Two Wood Poles.

		Total
2	Insulated eyebolts, at $0.16	$0.32
1	Straight line hanger, W. E. type A or equal, at $0.40	0.40
1	Ear, 12-in. clinch, at $0.25	0.25
1	Wood strain, 1¼-in. by 9½-in., at $0.15	0.15
40	Ft. 5/16-in. span wire, at $0.008	0.32
	Labor	2.00
		$3.44
	Incidentals and waste at 5%	0.17
	Total	$3.61

P. Two Trolleys — Center Pole Construction — One Iron Bracket Pole.

		Total
2	Straight line hangers, W. E. type A or equal, at $0.40	$0.80
2	Ears, 12-in. clinch, at $0.25	0.50
	Labor	2.50
		$3.80
	Incidentals and waste at 5%	0.19
	Total	$3.99

Q. Two Trolleys — Section Insulation — Center Pole Construction — One Iron Bracket Pole.

		Total
2	Section insulators (Phila. type), at $4.50	$ 9.00
2	Brooklyns (medium, malleable iron), at $0.60	1.20
	Labor	2.50
		$12.70
	Incidentals and waste at 5%	0.64
	Total	$13.34

R. Two Trolleys — Feeder Tap — Center Pole Construction — One Iron Bracket Pole.

		Total
2	Straight line hangers, W. E. type A or equal at $0.40	$ 0.80
2	Ears, 12 in. feed tap (cast lug), at $0.30	0.60
20	Ft. 4/0 w. p. wire, at $0.18	2.36
	Labor	2.50
		$ 6.26
	Incidentals and waste at 5%	0.31
	Total	$ 6.57

S. Two Trolleys — Under Elevated Structure.

		Total
2	Guide troughs, 30 in. by 12 in. by 3 in. wood, at $1.50	$ 3.00
2	Barn hangers, at $0.40	0.80
2	Ears, 12 in. clinch, at $0.25	0.50
	Labor	1.50
		$ 5.80
	Incidentals and waste at 5%	0.29
	Total	$ 6.09

T. Two Trolleys — Under Elevated Structure.

		Total
2	Guide troughs, 30 in. by 12 in. by 3 in. wood, at $1.50	$ 3.00
2	Barn hangers, at $0.40	0.80
2	Ears, 12 in. feed tap (cast lug), at $0.30	0.60
12	ft. 2/0 w. p. wire, at $0.077	0.93
	Labor	1.50
		$ 6.83
	Incidentals and waste at 5%	0.34
	Total	$ 7.17

In appraising the transmission line the construction was separated into the following types of spans:

A. Two trolleys — span construction — two iron poles.
B. Two trolleys — section insulators — span construction — two iron poles.
C. Two trolleys — feeder span construction — two iron poles.
D. Two trolleys — span construction — one iron and one wood pole.
E. Two trolleys — section insulators — span construction — one iron and one wood pole.
F. Two trolleys — feeder span construction — one iron and one wood pole.
G. Two trolleys — span construction — two wood poles.
H. Two trolleys — feeder span construction — two wood poles.
I. Two trolleys — section insulators — span construction — two wood poles.
K. One trolley — span construction — two iron poles.
N. One trolley — span construction — one iron and one wood pole.
O. One trolley — span construction — two wood poles.
P. One trolley — center pole construction — one iron bracket pole.
Q. One trolley — section insulators — center pole construction — one iron bracket pole.
R. One trolley — feeder tap — center pole construction — one iron bracket pole.
S. Two trolleys — under elevator structure.
T. Two trolleys — feeder tap — under elevated structure.

In inventorying the line these general types of span were estimated and also every variation of type. For example, an estimate was made of general type A and of 24 variations of this type. Usually these variations are in minor details and change the cost per span only a fraction, so that we give here only the itemized costs of the general types as in Table XVIII.

In estimating the wearing life of trolley wire, 1/0 was assumed to have a wearing value of 80½ lbs. per 1,000 ft. and 2/0 of 106.8 lbs. In a few instances the trolley wire was found to have reached

the estimated wearing value, and to be in need of removal, but still in service. The report, therefore, indicates it as having "excessive wearing value."

Feeder System.— On account of the absence of data on the year of installation or renewals of feeders, and on the interchange of wire from and to the various sections, each section was inspected to determine the present worth. A summary of the valuation of the feeder system is given in Table XX.

Bonding.— In estimating the cost of electrical track bonding, the various types of track and special work were inspected, and the quantity, size, and kind of wire, etc., used were noted in detail, and in depreciating the life of 20 years was taken. Table XXI gives the amounts and values for electrical track bonding.

Conduit Line.— The small amount of conduit line was estimated as follows:

Material	Cost new
7,912 ft. of 6-duct conduit and 18 manholes	$ 9,494.40
Organization, engineering and incidentals, 15%	1,424.16
	$10,918.56

TABLE — FEEDER SYSTEM

Material	Cost new
Feeder, copper, 1,745,559 feet (330.586 miles)	$367,942.83
Feeder, labor, 330.586 miles ($72.01 average per mile)	23,807.04
Feeder, equipment, part 1	50,599.92
Feeder, equipment, part 2	6,506.27
Feeder, equipment, part 3	4,881.44
Feeder, equipment, part 4	18,715.10
Feeder, equipment, part 5	75.31
Feeder, equipment, part 6	395.22
Feeder, equipment, part 7	614.78
Feeder, equipment (C. & P.)	1,863.73
	$475,401.64
Organization, engineering and incidentals, 15%	71,310.25
	$546,711.89
Storeroom stock, Center and Racine Aves.	2,149.69
Total	$548,861.58

Weight of Materials for Span Wires. Data, January, 1914. The following materials usually make up the span on double track construction.

4 — strain insulators.
2 — straight line hangers.
2 — trolley ears.
— seven-trand galvanized iron wire.

Straight-line hangers	3.25	lb. each
Ears	0.8	lb. each
¼-in. galvanized wire, 7-strand	0.125	lb. per ft.
5/16-in. galvanized wire, 7-strand	0.21	lb. per ft.
⅜-in. galvanized wire, 7-strand	0.295	lb. per ft.
7/16-in. galvanized wire, 7-strand	0.415	lb. per ft.
4/o trolley wire per ft.	0.6393 lb.	

3/0 trolley wire per ft.	0.5073 lb.
2/0 trolley wire per ft.	0.4024 lb.
1/0 trolley wire per ft.	0.3194 lb.
Strain insulators	2.25 lb. each

Unit Costs of Overhead Construction. The following are estimated costs of trolley line work on the Pacific Coast prior to the war.

Plain Insulated Span Wires.

Hauling and distributing: Two helpers at $0.30 per hr., with a team and teamster at $0.75 per hr. can cut and distribute 24 span wires per hr., at a cost of $0.044 per span wire. Use $0.05.

Making Up: One lineman at $0.50 per hr., using a helper at $0.30 per hr. one-half of the time, can make up one span, with one eyebolt and two strain insulators, four spans in one hr., at a cost of $0.16 per span.

Placing: One lineman at $0.50 per hr., using a helper at $0.30 per hr. half the time can bore the holes and place wire in 30 mins., at a cost of $0.32 per span.

Foreman's time: Allow 10% of the above labor cost for foreman's time, amounting to $0.03 per span.

Material:	
45 ft. of 5/16 in. galvanized strand at $0.99 per C.	$0.45
2 5/8 in. by 14 in. eye bolts, at $0.08	0.16
2 wood strain insulators, at $0.23	0.46
Total material	$1.07
Labor:	
Hauling and distributing	0.05
Making up	0.16
Placing	0.32
Foreman	0.03
Total labor	$0.56
Total material and labor	$1.63

Straight Line Hangers:

Labor Placing: Two linemen at $0.50 per hr., and a team and teamster at $0.75 per hr., can place 6 straight line hangers, with ears, and line up the trolley in one hour.

Labor per hanger	$0.29
Foreman's time 10% of above	0.03
Total labor	$ 0.32
Material:	
1 straight line hanger	0.45
1 suspension ear	0.25
Total material	$0.70
Total material and labor	$1.02

Single Pull Hangers on Standard Curves:

Labor placing: Two linemen at $0.50 per hr., one helper at $0.30 per hr., and a team with teamster at $0.75 per hr. can make strand into ring, place hanger and ear and line up trolley at rate of 2 per hr.

Cost per hanger	$1.02
Foreman's time 10% of above	0.10
Total labor	$1.12

Material:

1 single pull hanger	0.45
1 suspension ear	0.25
30 ft. ¼ in. galvanized strand at $0.66 per C. ft.	0.20
0.6 wood strainer insulator, at $0.23	0.14
1 2 in. galvanized ring	0.08
Total material	$1.12
Total material and labor	$2.24

Single Pull Hangers on Old Curves:

Labor placing: Same crew as above will place hanger and ear and line up trolley at rate of 3 per hr.

Labor per hanger	$0.70
Foreman's time, 10% of above	0.07
Total labor	$0.77

Material:

1 single pull hanger	0.45
0.6 wood strain insulator at $0.23	0.18
1 suspension ear	0.25
20 ft. ¼ in. galvanized strand at $0.66 per C. ft.	0.13
Total material	$1.01
Total material and labor	$1.78

Double Pull Hangers on New Curves:

Labor placing: Same crew as above will place hanger and ear, make strand into ring and line up the trolley at the rate of 1½ per hour.

Labor per hanger	$1.37
Foreman's time, 10% of above	0.13
Total labor	$1.50

Material:

1 double pull hanger	0.51
1 suspension ear	0.25
1 wood strain insulator	0.23
35 ft. ¼ in. galvanized strand, at $0.66 per C.	0.23
1 2 in. galvanized iron ring	0.08
Total material	$1.30
Total material and labor	$2.80

Double Pull Hangers on Old Curves:

Labor placing: Same crew as above will place hanger and ear and line up the trolley at the rate of 2 per hr.

Labor per hanger	$1.02
Foreman's time, 10% of above	0.10
Total labor	$1.12

Material:

1 double pull hanger	0.51
1 suspension ear	0.25

1 wood strain insulator	$0.23
25 ft. of ¼ in. galvanized strand, at $0.66 per C.	0.17
Total material	$1.16
Total material and labor	$2.28

Bridge Hangers:

Labor placing: One lineman at $0.50 per hour and one helper at $0.30 per hour can place hanger and ear and hang up trolley at rate of 5 per hr.

Labor per hanger	$0.16
Foreman's time, 10%	0.02
Total labor	0.18

Material:

1 bridge hanger	0.42
1 suspension ear	0.25
Total material	$0.67
Total material and labor	$0.85

Double Pull Hangers in Spans:

Labor placing: Two linemen at $0.50 per hr., with a tower wagon and driver at $0.75 per hr., can set a double pull hanger and ear in a straight span and line trolley in 20 mins.

Labor per hanger	$0.58
Foreman's time, 10% of above	0.06
Total labor	$0.64

Material:

1 double pull hanger	0.51
1 suspension ear	0.25
Total material	$0.76
Total material and labor	$1.40

Trolley Circuit Breakers:

Labor placing: The same gang under same conditions will place circuit breaker in 30 mins., at a cost of $1.13

Material:

1 trolley circuit breaker	$3.50
Total material and labor	$4.63

Trolley Strain Guys:

All guys for holding switch-pans, curves, and trolley, etc., in place are designated as "Strain Guys."

Labor placing: The same gang as above under same conditions will make up and place a strain guy in 20 mins.

Labor per guy	$0.71

Material:

1 wood strain insulator	0.23
60 ft. 5/16 in. galvanized strand, at $0.99 per C.	0.59
Total material	$0.82
Total material and labor	$1.53

Trolley Strain Plates:

Labor Placing:

1 lineman at $0.50 per hr.	$0.50
1 helper at $0.30 per hr.	0.30
can place 2 strain plates per hr. for	$0.80
averaging, each	0.40

Material:

1 strain plate	0.45
Total material and labor	$0.85

Crossings, Live:

Labor placing: Two linemen at $0.50 per hr., a helper at $0.30 per hr. with a team and teamster at $0.75 per hr. will place crossing while lining trolley in 30 mins., at a cost of	$1.03
Foreman's time, 10% of above	0.10
Total labor	$1.13
Material:	
1 live trolley crossing	3.25
Total material and labor	$4.38

Crossings, Insulated, Adjustable:

Labor placing: The same gang working under same conditions will place crossing in 1 hr., at a cost of	$2.26
Material:	
1 adjustable insulated crossing	4.05
Total material and labor	$6.31

Switch Pans:

Labor placing: The same gang working under same conditions will place switch pan in 30 mins., at a cost of	$1.13
Material:	
1 trolley switch pan	2.10
Total material and labor	$3.23

Trolley Section Switches:

Labor:	
1 lineman 1½ hrs., at $0.50	$0.75
1 helper 1½ hrs., at $0.30	0.45
	$1.20
Foreman's time, 10%	0.12
Total labor	$1.32
Material:	
1 200-amp. 600-volt switch and box	$6.50
25 ft. 2/0 w. p. wire at $0.0779	1.95
6 insulators at $0.17	1.02
6 standard pins at $0.02	0.12
½ lb. solder at $0.20	0.10
Miscellaneous material	0.10
Total material	$9.79
Total material and labor	$11.11

Cost of Signal Apparatus.

Stringing Block Wire: The cost of labor and material per loop mile of #10 w. p. iron wire is $83.75. Placing Block Lights and connecting:

1 lineman, 2 hrs., at $0.50	$1.00
2 helpers, 2 hrs., at $0.30	1.20
Total, 2 hrs.	$2.20

In 2 hrs. this gang place and connect two block lights, an average of $1.10 each. This allows for time used in moving from one end of block to the other.

Hauling: Block lights are placed after the system is in operation. On the basis of $0.30 per car mile a lineman and helper can distribute 30 block lights per day. The car travels 40 miles in a day.

40 miles at $0.30	$12.00
1 lineman	4.00
1 helper	2.40
Total for 30 block lights	$18.40

The average per block is $0.61.

Summary:

1 set block lights	$230.00 [1]
120 ft. w. p. iron wire, at $0.006	0.72
2 ⅝-in. machine bolts at $0.05	0.10
4 ⅝-in. round washers	0.01
12 porcelain knobs at $0.01	0.12
4 locust pins at $0.02	0.08
2 2-pin cross arms at $0.35	0.70
10 ft. wood moulding at $0.02	0.20
4 standard glass insulators at $0.04	0.16
Total material	$232.09
Labor placing and connecting	$ 1.10
Hauling	0.61
Labor on switch	2.00
Total materials and labor	$235.15

Hand Operated Semaphores:

The approximate cost of labor and material is $10.

Placing overhead switches:

1 lineman, 8 hrs., at $0.50	$ 4.00
1 helper, 8 hrs., at $0.30	2.40
12 car miles at $0.30	3.60
Total per day	$10.00

This gang can place 5 overhead switches, an average of $2.00 each. This includes time of moving from one end of block to the other.

Summary:

1 switch	$12.50
80 ft. #10 w. p. iron wire at $0.006	0.48
4 std. glass insulators at $0.04	0.16
4 locust pins at $0.02	0.08
Labor	2.00
Total material and labor	$15.22

Overhead Signal Switches:

Labor Placing: Signal switches are placed after the switches are in operation and a line car is used in distributing material. Car mileage is figured at $0.30 per mile and the crew will cover about 5 miles per day.

[1] This price is for light only. A light and disc semaphore costs about $25 more.

1 foreman, 8 hrs., at $0.56	$ 4.48
2 linemen, 8 hrs., at $0.50	8.00
2 helpers, 8 hrs., at $0.30	4.80
5 car miles, $0.30	1.50
Total labor for 10 switches	$18.78
Labor per switch	$ 1.88

Material:

1 switch	$ 2.50
60 ft. 5/16-in. gal. strand. at $0.99 per C.	0.59
2 5/8-in. by 14-in. eye bolts, at $0.08	0.16
2 insulators, at $0.23	0.46
1 feeder type tap ear	0.25
40 ft. 2 pr. #6 standard r. c. copper, at $0.07	2.80
Solder, tap and misc. material	0.25
Total material	$ 7.01
Total material and labor	$ 8.89

Cost Knife Switch:

1 600 volt, 600 ampere knife switch	$10.50
25 ft. 300 M. cir. mils. cable, at $0.176	4.40
6 insulators, at $0.17	1.02
6 pins, at $0.02	0.12
½ lb. solder at $0.20	0.10
Switch box	1.50
Misc. material	0.10
Total material	$17.74
1 lineman, 1½ hrs., at $0.50	0.75
1 helper, " " " 0.30	0.45
Foreman's time, 10%	0.12
Total material and labor	$19.06

Overhead signs. These will be placed after the system is in operation. On the basis of $0.30 per car-mile one motorman and one lineman can place 65 signs in two days, covering about 75 mis. It will take about 10 hrs. of this time running the car, but this is included in the $0.30 for car mileage. The remaining 6 hrs. are used in placing the 65 signs.

75 mi. at $0.30	$22.50
1 lineman 6 hrs. at $0.50	3.00
1 motorman, " " 0.30	1.80
Total for 65 signs, at $0.42	$27.30

The signs cost about $0.50, hence the total cost is $0.92 in place.

Cluster Lights:

1 lineman at $4.00 and one helper at $2.40 can install 4 clusters per 8 hr. day, averaging	$1.60
1 bracket and reflector	3.00
5 16-cp. 120-volt lamps, at $0.15	0.75
1 3-ampere 600-volt switch and fuse block	0.43
10 ft. wood moulding, at $0.02	0.20
2 lag screws, at $0.017	0.03
10 ft. #10 w. p. iron wire, at $0.006	0.06
1 glass insulator	0.04
Total material and labor	$6.11

Feeder Taps on Single Track:

Labor placing: The same gang as for overhead signal switches will make up, place on poles and tap to trolley and feeder in 1 hr., at a cost of	$2.26

Material:

15 ft. of 5/16-in. galvanized strand, at $0.99 per C.	0.15
35 ft. 2/0 double braid w. p. copper, at $16.40 per C	4.11
2 5/8-in. by 12-in. eye bolts, at $0.08	0.16
2 wood strain insulators, at $0.23	0.46
1 feeder tap hanger and bolt	0.30
1 suspension bar	0.25
Tape, solder, paste, etc.	0.05
Total material	$5.48
Total material and labor	$7.74

Feeder Taps on Double Track:

Labor placing: Allow 15 mins. additional time over single track for placing extra hanger and ear, making 1¼ hours, at a cost of $2.75	$2.75

Material:

Same as single track	$5.48 plus
1 feeder tap hanger and bolt	0.30
1 suspension ear	0.25
Total material	$6.03
Total material and labor	$8.78

Feeder Taps on Mast Arm Construction:

Labor Placing: This gang can make up and place and tap to feeder and trolley in 1 hr.

1 lineman, 1 hr., at $0.50	$0.50
1 helper, 1 hr., at $0.30	0.30
	$0.80
Add 10% for foreman's wages	0.08
Total labor	$0.88

Material:

15 ft. 2/0 w. b. w. p. copper	$1.14
1 feeder tap hanger and bolt	0.30
1 suspension ear	0.25
Tape, solder, paste, etc.	0.05
Total material	$1.74
Total material and labor	$2.62

Mast Arms:

Labor Placing: Allow for distributing $0.10 per mast arm. One lineman at $0.50 and a helper at $0.30 per hr. will place mast arm ready for hanger in 30 mins. at a cost of $0.40.

Total labor	$0.50

Material:

1 mast arm	$2.40
2 ½-in. by 3½-in. lag screws, at $0.013	0.03
8 ft. of ¼ in. galvanized strand, at $0.66 per C.	0.05
1 5/8-in. by 14-in. eye bolt	0.08
Total material	$2.56
Total material and labor	$3.06

Mast Arms — Angle Iron:

Labor placing:	
Same as above	$0.50
Material:	
1 Mast arm	2.50
Total material and labor	$3.00

Steady Strain Arms:

Labor, placing and distributing	$0.13
Material:	
1 strain arm	0.90
1 strain ear	0.22
	$1.12
Total material and labor	$1.25

Messenger Insulators:

Labor placing	$0.03
Material:	
1 insulator and pin	0.57
Total material and labor	$0.60

Catenary Construction:

Labor:	
Labor per mile	$113.20
Train rental and power	12.00
Total labor	$125.20
Material:	
1 mile 7/16-in. gal. strand, at $0.01 per ft.	$ 52.80
1 mile (3,392 lbs.) 4/0 grooved trolley, at $15.90 per lb.	537.74
352 gal. catenary hangers, at $23 per C.	88.00
Total material	$678.54
Total material and labor	$803.74

Trolley wire 1/0 Round:

Labor placing:	
Unloading, per mile	$ 0.25
Hauling to job, per mile	2.00
Two linemen at $0.50 per hr. and one helper at $0.30 per hr. and two teams and teamsters at $0.75 per hr. can string, pull up and tie to spans, with iron wire, one mile of trolley wire in 8 hrs., at a cost of	22.40
Foreman's time, 10% of above	2.50
Total labor	$27.15
Material:	
1 mile of 1/0 round copper trolley	264.49
Total materials and labor	$291.64

Trolley wire 2/0 Round:

Labor placing:	
Same as 1/0, except add $0.50 per mile for hauling.	
Total labor	$27.65

Material:	
1 mile 2/0 round copper trolley (2,128 lbs.)	330.03
Total material and labor	$357.68

Feeder, 250 M. cir. mil., Triple Braid, W. P.:

1 team and teamster and 1 helper can haul 1 load for $3.60 as there are two reels of 1,600 ft. each per load, the cost per mile is	$ 5.94
Stringing, tying and splicing	59.14
Total labor per mi.	$ 65.08
Material:	
1 mile cu. mil. stranded copper wire (5,343 lbs.), at $16.15 per C. lbs.	$852.72
47 tie wires, at $0.05	2.35
47 insulators, at $0.08	3.76
47 locust pins, at $0.02	0.94
Miscellaneous material	0.50
Total material	$860.27
Total material and labor	$925.35

Feeder, 250 M. cir. mil. Bare Stranded:

Crew: 1 team and teamster and 1 helper can haul one load for $3.60. As there are two reels of 1,800 ft. each per load, the cost per mile is	$ 5.28
Stringing, tying and splicing	59.14
Total labor	$ 64.42
Material:	
1 mile cir. mil. stranded copper wire, (4,026 lbs.), at $16.15 per C. lbs.	$650.20
47 tie wires, at $0.05	2.35
47 insulators, at $0.08	3.76
47 locust pins, at $0.02	0.94
Miscellaneous material	0.50
Total material	$657.75
Total material and labor	$722.17

Feeder, 350 M. cir. mil.—Bare Stranded:

Hauling:	
1 team and teamster, 1 day	$ 6.00
1 helper, 1 day	2.40
2½ loads per day, at $3.35	$ 8.40
Add $0.25 for unloading equals $3.60 per load.	
As there are 2 reels of 1,700 ft. each per load, the cost per mile is	$ 5.60
Stringing, tying and splicing	55.47
Total labor	$ 61.07
Material:	
1 mile stranded copper wire (5,636 lbs.), at $16.15 per C. lbs.	$921.45
47 tie wires, at $0.05	2.35
47 insulators, at $0.08	3.75
47 locust pins, at $0.02	0.94
Miscellaneous material	0.50
Total material	$928.99
Total material and labor	$990.06

Grounds, 500 M. Cir. Mils.:

Material:	
75 ft. of wire, at $0.28	$21.00
35 ft. of 2-in. iron pipe, at $0.108	3.80
Miscellaneous material	2.00
Total material	$26.80
Labor:	
Digging and refilling trench	$ 2.50
Placing iron pipe	0.20
Splicing (1 splice)	0.25
Bending (6 contacts)	0.50
	$ 4.20
Foreman, 10%	0.40
Total labor	$ 4.60
2.75 sq. yds. asphalt pavement, at $3.80	10.45
Total material and labor	$41.85
Unit cost per ft.	0.56

Grounds, 4/0 and 1/0:

Material:	4/0	1/0
55 ft. of wire	$6.45	$3.55
Miscellaneous material	0.35	0.25
Total material	$6.80	$3.80
Labor:		
Digging and refilling	$1.75	$1.75
Placing wire	0.25	0.25
Splicing (1 splice)	0.20	0.20
Bending (1 contact)	0.15	0.15
	$2.35	$2.35
Foreman, 10%	0.25	0.25
Total labor	$2.60	$2.60
Total material and labor	$9.40	$6.40

Track Bonding on an Interurban. The following was the cost of bonding an interurban road. The work consisted of removing the continuous rail joints on 60 and 70 lb. rails and Weber joints on other main line rails and angle bars on sidings, chipping rails with cold chisels where bonds were soldered, and putting on one 250,000 cir. mils. or one 4/0 Chase Shawmut soldered bond at each joint, and replacing rail joint.

New track bonded	12.792	miles with	2,058	(250,000 cir. mils.)	bonds
Old " "	10.513	" "	3,430	(mostly 4/0)	"
Total " "	23.305	" "	5,488		"

Cost of 5,488 Bonds:

Labor:	
287 hr., foreman, blacksmith, time-keeper, etc., at $0.41	$ 118.34
Miscellaneous labor other than construction crew	84.00
4,696 hr. labor on new line at $0.268	1,231.99
7,105 hr. labor on old line at $0.305	2,169.70
Total labor	$3,604.03

Material:

2,940 bonds 250,000 cir. mils. at $0.50	$1,470.00
2,548 bonds 4/0 cir. mils. at $0.495	1,258.72
	$2,728.72
Cable for cross bonds	85.18
Tools	137.00
Solder, 858 lb. at 23 ct.	197.52
Zinc, 150 lb. at 12 ct.	17.82
Gasolene, 840 gal. at 23½ ct.	197.50
Muriatic acid (42 gal. at 69 ct. and 234 lb. at 3.4)	39.30
Cotton rope and sash for wipers	3.90
Freight and cartage	39.09
Personal expense account	29.55
Temporary construction prorated	147.00
Superintendence not on pay roll	120.00
Total material	$3,742.58
Total material and labor	$7.346.61

This is equivalent to $0.66 for labor and $0.67 for material, or a total of $1.33 per bond.

Cost of Track Bonds, Street Ry. The following were the costs in a Pacific Coast city in 1906 to 1909.

Chase Shawmut Bond. 4/0:

Cost of bond	$0.294
Material (mis.)	0.030
Labor	0.080
Total material and labor	$0.404

Stranded Copper Bond, 3/0:

Cost of bond, 36 in. long at 18.03 ct. per lb.	$0.346
Labor	0.150
Material (misc.)	0.040
Total material and labor	$0.536

American Steel and Wire Co. Bond:

Cost of bond	$0.384
Material (misc.)	0.020
Labor	0.100
Total material and labor	$0.504

The detail cost of 120 B. B. bonds was as follows:

Material:

120 B. B. bonds at $0.50	$60.00
26 lb. solder at $0.19	4.94
15 gal. gasoline at $0.15	2.25
1½ gal. acid at $0.80	1.20
4 10-in. files at $0.12	0.48
1 White's blast	5.10
40 lb. 4/0 solid copper at $0.04¼	1.70
Total 120 bonds at $0.63	$75.67

The labor averaged $0.30 per bond, making a total of $0.93 per bond for material and labor.

Cost of Bonding, Chicago. The following costs are taken from tables in Engineering and Contracting, Oct. 5, 1910, and were used

in making the valuation of the properties of the Chicago Consolidated Traction Co., by B. J. Arnold and G. W. Weston.

2-joint bonds made of 2/0 stranded copper, 3 ft. long, cost $0.25 for labor, $1.10 for material, a total of $1.35 each. A scrap value of $0.14 was assigned to these.

Cross bonds, of 2/0 stranded copper, 23 ft. long, cost $0.80 each for labor and $1.40 for material, total of $2.20. To these was given a scrap value of $1.04.

Ground returns, 500 M cir. mils. stranded copper, length 2,640 ft., were given a labor cost of $17.50; material, $613.80; total, $631.30; and a scrap value of $447.15.

Ground returns, 1000 M cir. mils. stranded copper, length, 135 ft., cost $8.00 for labor; $63.20 for materials, a total of $71.20. Scrap value, $46.00.

Cost of Bonding. The following were the costs of jobs done on a railway in Washington in 1910. Wages were 30 cts. per hr.

TABLE XIX. COST OF BONDING

No. of bonds	Kind of bonds	Unit cost: Bond	Misc. mat'l.	Labor	Total
190	Old 500 M.C.M. cable, 62 lb. at $0.20	$0.065	$0.$38	$0.145	$0.248
120	8-in.	0.230	0.032	0.086	0.348
5	B.B.	0.490	0.052	0.150	0.692
10	Home made	0.097	0.053	0.150	0.300
6 }	Home made	0.290			
160 }	B. B.	0.490	0.031	0.175	0.688
4	Home made (3.5 lb. at $0.15)	0.525			
50	B. B.	0.490	0.134	0.204	0.831
300	8 in.	0.220	0.023	0.184	0.427
30	Home made 2/0 cable (1.8 lb. at $0.16¼)	0.292	0.059	0.210	0.561
142	B. B.	0.490	0.072	0.164	0.726
26	8 in.	0.220	0.047	0.096	0.363
70	B. B. 4/0	0.400	0.029	0.136	0.565
32	Home made small cable	0.162	0.045	0.082	0.289
272	8 in.	0.220	0.032	0.106	0.358
150	Channel pin	0.275		0.050	0.325

Cross Bonds. The following costs are the averages from job records:

Single track; length 5 ft.

5½ lb. M.C.M. cable at $0.18	$1.00
Material, solder, gasoline, solder, etc.	0.50
Labor	0.50
	$2.00

Double track, 12-ft. centers; length 21 ft.

	4/0	300 M.C.M.	500 M.C.M.
35 lb. cable at $0.18	...	...	$6.30
22 " " " "	...	$3.95	...
15 " " " "	$2.70	...	...
Misc. material	0.75	1.00	1.50
Labor	1.00	1.00	1.25
	$4.45	$5.95	$9.05

TABLE XX. COST OF BONDING SWITCHES AND FROGS

Am't. and kind of Bonding mat'l. used	Bonding mat'l.	Misc. mat'l.	Labor	Total
29 lb. 300 M.C.M. W. P. cable at $0.16¼ per lb.	$4.71	$2.33	$1.25	$8.29
42 lb. 500 M.C.M. W. P. cable	6.83	2.44	3.30	12.57
72 lb. 500 M.C.M. W. P. cable at $0.29	20.88	4.35	3.00	28.23
145 lb. 500 M.C.M. W. P. cable at $0.29	21.02	4.26	3.00	28.28
65 lb. 500 M.C.M. W. P. cable at $0.29; 7½ lb. 4/0 bare cable at $0.15	19.97	4.48	4.00	28.45
13 lb. 4/0 bare cable at $0.15; 21 lb. 300 M.C.M. bare cable at $0.15	2.80	1.27	3.01	7.08
172 lb. 300 M.C.M. W. P. cable at $0.29	12.47	3.70	4.75	20.92
36 lb. 4/0 bare cable at $0.15; 14 lb. 500 M.C.M. W. P. cable at 0.16¼	3.83	2.53	3.75	10.11

Cost of Bonding. C. D. Wesselhoeft, in Data, June, 1915, gave the following.

	Cost per joint		
	Labor	Material	Total
2 — 500,000 cir. mil. bonds soldered to head of third rail	$0.66	$1.23	$1.89
2 — 500,000 cir. mil. pin-expanded concealed bonds applied to track rail	0.69	2.05	2.74
2 — 400,000 cir. mil. compressed terminal concealed bonds applied to track rail	...	...	1.90
2 — 0000 bonds compressed terminal concealed bonds applied to track rail	0.50	1.00	1.50

Railway Cars. The following costs are from the accounting records of a railway company on the Pacific Coast, which was appraised by H. P. Gillette in 1911. The trucks were standard gage, 4 ft. 8½ ins.

PASSENGER CARS

Exclusive of Electrical Equipment.

Bodies: Closed single truck type, length 16 ft., over all 24 ft., width over sills 6 ft., over all 7 ft. by 4½ ins. Length of each platform 3 ft. 6 ins. Height to trolley board 11 ft.
Trucks: Single, 7 ft., 6 ins. wheel base, Lobdell C–61 wheels, 33-in. diam., 3-in. tread, 1 in. by 1 in. flange, 4 in. axles.
Brakes: Brill lever.
Cost, each car $1,850

Bodies: Closed single truck type, length 22 ft., over all 31 ft., each platform 4 ft., width over sills 6 ft. 6 ins., over all 7 ft. 8 ins. Height of trolley board above rail 11 ft. 10 ins.
Trucks: Single, 8 ft. 6 ins., wheel base with spoke wheels of 33-in. diam., 3-in. tread, 1-in. by ⅞-in. flange, 4-in. axle.
Brakes: Vertical wheel and gear.
Cost, each car $2,800

Bodies: Open, single truck type, length 25 ft., over all 27 ft. 6 ins., width over sills 6 ft. 2 ins., over all 7 ft. 10 ins. Height to trolley board, 11 ft.
Trucks: Single, 7 ft. wheel base, spoked wheels, 30-in. diam. 3-in. tread, flange 1-in. thick, 3⅜-in. axles.
Brakes: Lever.
Cost, each car $1,600

Bodies: Open, single truck, type, length over all 27 ft., width over sills 6 ft. 2 ins. over all 7 ft. 10 ins., height to trolley board 11 ft.
Trucks: Single 6 ft. 10½ ins., wheel base, spoked wheels, 33-in. diam., 3-in. tread, 1-in. by 1-in. flange, 3⅜-in. axles.
Brakes: Old fashioned hand wheel.
Cost, each car $1,600
Bodies: Trailer made by railway co. Closed vestibule, single truck type, length 21 ft., over all 31 ft. 10 ins. Length of each platform 4 ft. 3 ins. Width over sills 6 ft. 1 in., over all 7 ft. 7 ins., height to trolley board 10 ft. 10 ins.
Trucks: Single, 8 ft. 6-in. wheel base with spoke wheels, 3 ft. 3-in. diam., 3-in. tread, 1-in. by 1-in. flange, 4-in. axles.
Brakes: Lever type.
Cost, each car $1,850
Bodies: Combination open and closed single truck type, length 29 ft., over all 30 ft., each platform 10 ft. width over sills, 6 ft. 2 ins., over all 8 ft. 1½ ins. Height of trolley board above rail 11 ft. 3 ins.
Trucks: Single 8 ft. wheel base with spoke wheels of 33-in. diam., 3-in. tread, 1-in. by 1-in. flange, 4-in. axles.
Brakes: Vertical hand wheel.
Cost, each car $2,200
Bodies: Closed, single truck type, length 21 ft., over all 31 ft. Length of each platform 4 ft., width over sills, 6 ft. 5 ins., over all 7 ft. 8 ins. Height to trolley board 11 ft. 8 ins.
Trucks: Single 8 ft. wheel base, with spoke wheels of 33-in. diam., 3-in. tread, 1-in. by 1-in. flange, 4-in. axles.
Brakes: Vertical wheel and gear.
Cost, each car $2,200
Bodies: Open double truck type, length over all 44 ft., width over sills, 7 ft. 4½ ins., over all 9 ft., 6 ins. Height of trolley board above rail. 10 ft. 9 ins.
Trucks: Double, 4 ft. wheel base, with wheels 33-in. diam., 3-in. tread, flange 1-in. by 1-in and 4-in. axles.
Cost, each car $2,350
Bodies: Closed, double truck type. Length 32 ft., over all 41 ft. 6 ins., length of each platform 4 ft. 8 ins., width over sills, 7 ft. 2 ins., over all 7 ft. 4 ins. Height of trolley board above rail 11 ft. 10 ins.
Trucks: Double, 4 ft. wheel base with wheels 33-in. diam., 3-in. tread, 1-in. by 1-in. flange, 4-in. axles.
Brakes: Straight air brakes and hand brakes.
Cost, each car $3,150
Bodies: Closed, monitor roof, double truck type. Length 35 ft., over all 47 ft., length of each platform 5 ft. 6 ins., width over sills 8 ft. 3 ins., over all 8 ft. 4½ ins. Height of trolley board above rail. 12 ft.
Trucks: 2 double, 4-ft. wheel base with wheels 33-in. diam., ⅞-in. by 1-in. flange, 4½-in. axles.
Brakes: Straight air brakes.
Cost, each car $3,350
Bodies: Closed double truck type, length 35 ft., over all 47 ft., width over sills 8 ft. 2 ins., over all 8 ft. 4½ ins. Height of trolley board 11 ft. 6 ins.
Trucks: Double, wheel base 4 ft. 6-in. with cast iron spoke wheels of 33-in. diam., 3-in. tread, ⅞ by ¾-in. flange, 4½-in. axles.
Brakes: Allis-Chalmers.
Cost, each car $4,020

EXPRESS CARS

Bodies: Double truck express, length 41 ft., over all 43 ft. 6 ins., width over sills 8 ft. 2 ins., over all 8 ft. 6 ins., height of trolley board above rail 11 ft.

Trucks: Double 4-ft. wheel base with spoke wheels 33-in. diam., 3-in. tread, 1-in. by 1-in. flange, 4-in. axles.
Brakes: National air brakes and hand wheel.
Cost, each car $1,350

FLAT CARS

Bodies: Local make, single truck flat, length over all 16 ft. width over all 7 ft.
Trucks: Local single pedestal type with 7-ft. wheel base, spoke wheels, 30-in. diam., 3-in. tread, 1-in. by ¾-in. flange, 3⅜-in. axles.
Brakes: Horizontal hand wheels.
Cost, each car .... $ 550
Bodies: Double truck flat, length 40 ft., over all 43½ ft., width 7 ft. 10 ins. over all, fitted with pocket couplers.
Trucks: Jewett double with Standard (solid) wheels 33-in. diam., 4½-in. tread, 1½-in. flange and 4½-in. axles.
Brakes: Air brakes, inside wheels, metal brake beams.
Cost, each car $1,050
Bodies: N. P. make, flat, length 30 ft., over all 33 ft., width over sills 7 ft. 7 ins., over all 8 ft., fitted with American pocket couplers.
Trucks: Double with standard (solid) wheels 33-in. diam., 4½-in. tread, 1½-in. by 1½-in. flange, standard axles.
Brakes: Air — outside wheels, wood brake beams.
Cost, each car .... $ 700
Bodies: Local make flat, 33 ft. long, over all 35½ ft., width over sills 7½ ft., over all 7 ft. 1 in.
Trucks: Local make, double, with cast wheels, 24-in. diam., 4-in. tread, 1-in. by 1-in. flange, 3¼-in. axles.
Brakes: Hand wheel.
Cost, each car .... $ 600
Bodies: Local make flat, 41 ft. long, over all 43 ft. 5 ins., width over sills, 8 ft., over all 9 ft., pocket couplers.
Trucks: Double, with cast wheels 33-in. diam., 4½-in. tread, 1½-in. by 1½-in. flange, 5-in. axles.
Brakes: Air and wheel hand brakes.
Cost, each car .... $ 700

LINE CARS

Bodies: Local made, single truck box car with rising platform, length over all 22 ft., width over all 8 ft. 4 ins., height of trolley board above rail 11 ft. 5 ins. Inside filled with shelves and lockers.
Trucks: Single 7-ft. 6-in. wheel base, with spoked wheels 30-in. diam., 3-in. tread, 1-in. by 1-in. flange and 3½-in. axles.
Brakes: Hand wheel.
Equipment: 2-25 hp. motors, with inside suspension, pinion 14-T, gear 67-T, furnished with 2 K-10 controllers.
Cost, each car $2,300
Dump Cars: 6 yd., two-way dump gravel cars.
Cost, each car .... $ 420

ELECTRICAL EQUIPMENT OF CARS.

Two-motor equipments 35- or 38-hp. inside suspension, pinion 17-T, gear 67-T, furnished with 2 K-10 controllers, or 2 K-6 controllers.
Cost, each equipment $1,500
Four-motor equipments, 38 hp. outside suspension, pinion 17-T, gear 67-T, each equipment provided with 2 K-6 controllers.
Cost, each equipment $2,800
One-motor equipment, 15 hp., inside suspension, pinion 14-T, gear 67-T, furnished with K-10 controller.
Cost, each equipment $1,100

One-motor equipment, 25 hp., inside suspension, pinion 14-T, gear 67-T, furnished with 2 K-10 controllers.
Cost, each equipment $1,250
Four-motor equipments, 40 hp., outside suspension, pinion 17-T, gear 69-T, each equipment furnished with 2 K-28 controllers.
Cost, each equipment $2,375

Cost of Rolling Stock in Chicago. The following data are from the Chicago valuation report previously referred to, by B. J. Arnold and George Weston, year 1910.

CAR BODIES

CLOSED CARS

Semi-convertible with smoking compartment, Pay-as-you-enter type, price new, for body only, $3,441. These are Kuhlman double truck cars; length, over bumpers 47 ft. 6 ins. and over body 31 ft. 9 ins.; width, over all, 8 ft. 9 ins.; vestibuled platforms; monitor type roof. Seating capacity, 40; seats, 16 fixed cross, 4 longitudinal; 21 electric lights; 1 Calumet fender; passengers push buttons; 1 sand box; iron rod window guards; 2 Hunter adjustable illuminated signs in vestibule, 1 in side window; double end hand brakes, bevel geared hand wheel; double fare registers; 1 pair track scrapers.

The price new of a car very similar to the above except that it was not a Pay-as-you-enter, was $3,088 for body only.

Closed, passenger body, price new for body, $1,504. These are Pullman single truck cars, length, over bumpers, 30 ft. 6 ins., over body, 20 ft.; width, over all, 7 ft. 6 ins.; vestibuled platforms 50 ins. long; monitor type roof; seating capacity, 26; seats, longitudinal type; 10 electric lights; 2 Berg improved fenders; 2 Ham sand boxes; signs, end, 2 illuminated, Calumet pattern, side, brackets for 2 wood signs; hand brakes, double end, hand wheel; double fare register; 2 pair track scrapers.

The price of a similar car, length 18 ft. 8 ins. over body, and with a seating capacity of 24, was $1,418 for body.

OPEN CAR BODIES

The price new of an open, 16 bench body car, with 18 in. aisle between the rows of seats, was $1,317. These are St. Louis cars, single truck; length, over bumpers 27 ft. 2 ins. over corner posts, 17 ft. 9 ins.; width, over posts, 7 ft. 11 ins.; open platforms, 51 ins. long, monitor type roof; 4 entrances at platforms, 40 ins. wide; seating capacity, 32; seats, 16 reversible; 20 electric lights; wire screen side guards; brackets for sheet iron end signs and wood side signs; double end, rachet hand brakes; double fare register.

Open, 10 bench body cars, no aisle, were priced at $1,231.

The cars were made by the Pullman Co.; single truck; length, over bumpers, 30 ft., over corner posts, 20 ft.; width, over posts, 7 ft.; open platforms, 37 ins. long; monitor type roof; entrances on each side; seating capacity, 50; seats, 4 fixed at bulk-heads, 6 reversible with spindle backs; 10 electric lights; wire screen side

guards; brackets for 2 sheet iron signs on each end, for 2 wood signs on each side; double end, rachet hand brakes; fare registers.

The price of an open trailer of the same length and general type was $1,193. An open trailer, length, over bumpers, 27 ft. 4 ins., over body, 18 ft. 2 ins., and with a seating capacity of 45, was priced $1,058; one with a length of 23 ft. 8 ins. over bumpers and 17 ft. 3 ins. over the body and seating capacity of 40, $908.

MOTOR EQUIPMENTS

The following prices are for complete motor equipments, f.o.b. factory, for trolley cars.

Maker	Motors per equipment	Type	Hp. per motor	Price per equipment
G. E.	4	52 or 54	25	$1,874
G. E.	2	800	27	1,040
G. E.	2	W. P. 30	30	1,040
Ray	1	...	30	900
West.	1	Lorain	30	770
G. E.	2	W. P. 50	35	1,040
West.	2	Lorain	35	1,158
West.	4	"	35	2,168
G. E.	4	70 or 80	40	2,489
Ray	1	...	40	900

TRUCKS

The following prices are for trolley car trucks complete, f.o.b. factory:

		Price
McMcGuire pressed steel	sgl.	$250
McGuire A1 and A2 suspension	sgl.	275
Curtis	sgl.	275
Peckham, 7BX	sgl.	253
Lovejoy	sgl.	200
Brill 21E	sgl.	280
Taylor	sgl.	240
McGuire pedestal	sgl.	150
Du Pont	sgl.	250
Brill 27G	dbl.	625
Calumet MCB	dbl.	650
Pressed steel MCB	dbl.	700

MISCELLANEOUS CAR EQUIPMENT

	Price
Peter Smith heater No. 2 (installed)	$135
Germer heater No. 2 (installed)	125
Calumet stoves	22.50
Consolidated electric heaters	25
National air brakes, AA1 compressor	275
" " " D4 "	450
" " " upright "	300
Resistances for Mosher headlights	4.50
Mosher arc headlights	20
New Haven double fare registers	30
Hunter adjustable illuminated signs	20
Calumet pattern " "	5
Wooden deck signs	3
Automotoneers	12.50
25-lb. wrecking frogs	2.50

Motorman's stools	$1.25
Oil headlights	12.50

Summary of Rolling Stock:

119 box motor car bodies	$156,000
127 open " " "	131,600
43 open trailer bodies	39,300
5 box " "	5,500
294 passenger car bodies	$332,400
294 single trucks	72,920
199 motor equipments (2 motors each)	107,464
Total passenger cars	$512,784
50 miscel. service cars	42,082
Total	$554,866

Further details are given in Engineering and Contracting, Sept. 28, 1910.

Weight and Price of Trucks. Table XXI was compiled from data gathered by Henry L. Gray in the course of making appraisals in the state of Washington.

TABLE XXI. COST OF STANDARD GAUGE TRUCKS FOR CARS

Wheel base Ft.	Ins.	Diam. wheels, ins.	Weight, lbs.	Cost, f.o.b. Factory
8	6	33	5900	$270
7	0	33	5500	260
4	0	34	6850	260
4	6	34 & 21	5260	246
8	0	33	5900	270
7	6	33	5500	260
4	6	34	7220	267
4	0	33	6790	260
4	0	34	6820	263
4	6	34 & 21	5200	281
4	6	34	7000	260
6	4½	34	7950	294
6	4½	34	8200	344
4	6	34 & 21	5500	280
5	10	34	7100	260

The above were prices prior to the world war.

Appraisal of the Elevated Railways of Chicago. Condensed from Engineering and Contracting, May 15, 1912.

These railways are the South Side Elevated, the Metropolitan West Side Railway, the Northwestern Elevated and the Chicago & Oak Park Elevated. A physical valuation of these properties was necessary to further progress of plans to arrive at a satisfactory scheme for the operation and maintenance of all the transportation facilities within the city. The City Council, through its committee on local transportation, Mr. Peter Reinberg, chairman, appointed the three members of the present Harbor and Subway Commission to undertake the valuation of the elevated railroad properties. This committee consisted of Messrs. John Erickson, E. C. Shankland and J. J. Reynolds. Mr. George Weston of the Board of Super-

vising Engineers was later added to the committee, which was known as the Valuation Committee. The representative of the Chicago elevated railways, who was also appointed as a member of this committee, was Prof. George F. Swain.

After several meetings of the Valuation Committee it was found that the members representing the city and the representative of the railways could not agree on all the methods of valuating the various items of physical property. Prof. George F. Swain therefore withdrew from the committee and presented an independent minority report. We give herewith tabular abstracts of the report of the Valuation Committee submitted to the Council committee on May 8, 1912, and the report of Prof. George F. Swain, submitted at the same time. The elevated lines, not including surface tracks, contain the following mileage:

282,000 ft.	double track
78,500 ft.	third "
38,000 ft.	fourth "
4,300 ft.	single "

COST OF REPRODUCTION NEW, ESTIMATED BY COMMITTEE

Items	
1. Real estate and right of way	$16,490,728
2. Foundations and public utilities	2,230,841
3. Structural steel	11,127,025
4. Track work	2,323,946
4A. Pavement	262,200
5. Third rail	318,483
6. Special work	185,957
7. Storage yards, including track, special work and interlocking	543,831
8. Interlocking plants and block signal	388,399
9. Power stations	3,962,672
10. Sub-stations and batteries	1,652,025
11. Transmission lines, overhead and bonding	1,192,366
12. Rolling stock	9,700,887
13. Stations, buildings and platforms	1,784,887
14. Office fixtures, tools and supplies	359,000
Taxes during construction	150,000
	$52,673,247
Add 18% overhead charges	9,481,185
Total	$62,154,433

The Committee estimated the depreciated value at $53,451,181.

COST OF REPRODUCTION NEW, ESTIMATED BY PROF. GEO. F. SWAIN

Items	
2. Foundations	$ 2,600,000
3. Structural steel	12,884,132
4. Track work	2,347,431
4A. Pavement	251,400
5. Third rail	329,700
6 Special work	189,775
7. Storage yards, including track, special work and interlocking	550,270
8. Interlocking plants and block signals	412,000
9. Power stations	4,166,325
10. Sub-stations and batteries	1,753,458

Items	
11. Transmission lines, overhead trolley and bonding ...	$ 1,360,104
12. Rolling stock ...	10,098,652
13. Stations, buildings and platforms ...	2,250,000
14. Office fixtures, tools and supplies ...	359,000
Total without real estate and rights of way, or overhead charge ...	$39,552,247
Overhead on physical [1] ...	11,865,674
Total without real estate and rights of way ...	$51,417,921
Real estate and rights of way (J. Milton Trainer's figures) ...	44,551,498
Brokerage on real estate and rights of way 5% ...	2,227,575
Total ...	$98,196,994

Prof. Swain estimated the depreciated value at $93,279,143.

[1] Percentages for cost of construction, organization, etc., included in item overhead on physical.

Cost of Contact-Rail Construction. The following data are quoted from the American Handbook for Electrical Engineers by Harold Pender. The estimates in Table XXII include the cost of (1) handling and distributing the material from the storehouse to the place where it is used; (2) the solder, gasoline, etc., used in bonding contact rail; (3) putting 3 coats of paint on the protection; (4) bending rails on curves; (5) 5% for breakage; (6) foremen's and engineers' salaries. They do not include the cost of tools or of jumpers.

These estimates are approximately correct where existing traffic does not materially impede the work. Under less favorable conditions the cost may rise 50% or more over the figures given.

The estimate on the top-contact type is based upon the Interborough Rapid Transit Co.'s construction, New York (Stillwell-Slater patent), the wt. of rail, however, being slightly less than on that railway. The estimate of the under-contact type is based upon construction similar to that used by the New York Central R. R. (Wilgus-Sprague patent).

TABLE XXII. COST PER MILE OF CONTACT-RAIL CONSTRUCTION

	Top contact		Under contact	
Material:	Amount	Cost	Amount	Cost
Rail, 70 lb. ...	55 tons	$1,815	55 tons	$1,815
" special ...	...	...	1.2	40
Inclines ...	11	47	11	47
Insulators, std. ...	511	92	1,000	165
" special ...	...	...	25	13
Brackets or pedestals ...	515	62	500	250
Brackets, special ...	...	...	15	7
Bolts ...	515	10	515	90
Lag screws ...	1,030	20	1,515	30
Clips ...	1,030	41	...	...
Drive screws ...	...	...	80 gross	24
Soldered bonds ...	350	168	350	168
Splice plates and bolts ...	350	53	180	31
Protection ...	...	793	...	642

	Top contact Amount	Top contact Cost	Under contact Amount	Under contact Cost
Material:				
Paint	...	$49	...	$82
Felt separator	...	...	...	2
Long ties, excess only[1]	505	177	505	177
Total		$3,327		$3,583
Labor:				
Installing, bonding and protection of third rail		800		1,000
Installing long ties		101		101
Total		$901		$1,101
Total		$4,228		$4,684

[1] This item includes only the difference in cost between the long ties which carry the insulators and the cost of the same number of standard ties.

Cost of Grinding Rail Corrugations and Joints. The following data are quoted from the Electric Railway Handbook by Albert S. Richey. Mr. C. L. Crabbs gives the following cost data covering 1 year's work on track of the Brooklyn Rapid Transit Co. The average cost per ft. of grinding 21,725 lin. ft. of corrugation of an average depth of 0.01 in. was: labor, $0.112; material, $0.0227; total, $0.1347. During the same period, 1,418 joints and dishes of a depth approximately 0.05 in. were ground, the average cost per joint being: labor, $0.8322; material, $0.193; total, $1.0252. This work was done with a reciprocating grinder, but Mr. Crabbs states that his experience with considerable grinding of joints with wheel machines shows very nearly the same costs.

CHAPTER XXI

MISCELLANEOUS

Asbestos. The following are costs of various asbestos materials. *Asbestos building felt* and *sheathing* in less than ton lots costs 3½ cts. per lb. for the light material weighing from 6 to 30 lbs. per 100 sq. ft.; 4 cts. per lb. is charged for the heavy asbestos weighing from 45 to 56 lbs. per 100 sq. ft.

Mill board is made in standard sheets, 40 × 40 ins., and 41 × 40 ins. It varies in thickness from 1/32 to ½ in. and in weight from 2 to 27 lbs. per sheet. The net price in 100-lb. lots is 5 cts. per lb.

Transite, asbestos wood, used for fireproofing, ventilators and smoke jackets, comes in standard sheets, 36 × 48 ins. and 42 × 96 ins. The prices f.o.b. factory are as follows:

Thickness, ins.	Weight, lbs.	Price per sq. ft.
⅛	1	$0.08
¼	2	.16
⅜	3	.28
½	4	.32
⅝	5	.40
⅞	7	.48
1	8	.52
1½	12	.64
2	16	.80

Asbestos cements are used for covering boilers, domes, fittings, etc., and all irregular surfaces, and may be used over asbestos air cell boiler blocks, when it makes an excellent covering. When mixed with water to a consistency of mortar and applied with a trowel, it forms a light porous coating which is the most efficient non-conductor. The cost of this cement is $33 per ton.

Chain. Prices per 100 lbs., f. o. b. Pittsburg, are as follows:

MACHINE MADE CHAIN

Size, ins.	Proof	BB	BBB
3–16	$8.25	$9.50	$10.00
¼	5.70	6.95	7.45
5–16	4.70	5.95	6.45
⅜	4.15	5.40	5.90
7–16	3.85	5.10	5.60
½ and 9–16	3.65	4.90	5.40
⅝	3.55	4.80	5.30
¾	3.45	4.70	5.20
⅞	3.35	4.60	5.10
1	3.25	4.50	5.00
1¼ and 1⅛	3.35	4.60	5.10

HAND-MADE CHAIN

Size, ins.	BBB crane chain.	BBB crane, dredge hoisting or steam shovel hoisting chain.	Special "Warwick" crane, hoisting steam shovel hoisting and dredge hoisting chain.	Special "Trident" crane, steam shovel hoisting and dredge hoisting chain.
5/8	$7.95	$8.20	$9.15	$9.15
3/4	7.15	7.45	8.45	8.45
7/8	6.70	6.90	7.95	...
1	6.15	6.40	7.45	...
1 1/8	5.75	5.95	6.90	...
1 1/4	5.65	5.90	6.85	...
1 3/8 to 1 7/8	5.55	5.75	6.80	...

Chain Blocks. Chain blocks kept well oiled and kept under cover where grit and dirt cannot enter the gears should have a life of from 5 to 20 years. On outside work where sand and grit is allowed to enter the gears the life of a block is reduced very much, and repairs may cost as much as 50% of the first cost annually.

TRIPLEX BLOCKS

Capacity in tons	Hoist in feet	Weight, lbs. (net)	Price	Extra hoist per ft.
1/2	8	53	$ 28	$0.72
1	8	80	36	.76
1 1/2	8	124	48	.80
2	9	188	56	.84
3	10	200	72	1.20
4	10	290	88	1.28
5	12	380	112	1.72
6	12	390	132	1.72
8	12	470	160	2.16
10	12	570	192	2.60
12	12	800	240	3.44
16	12	1,000	288	4.32
20	12	1,375	315	5.20

Sizes 3 to 20 tons have a lower as well as an upper block.

DUPLEX BLOCKS

Capacity in tons	Hoist in feet	Weight, lbs. (net)	Price	Extra hoist per ft.
1/2	8	43	$ 21.25	$1.00
1	8	57	25.50	1.27
1 1/2	8	76	34.00	1.50
2	9	104	42.50	1.70
3	10	200	63.75	1.85
4	10	225	80.75	2.05
5	12	340	119.00	2.55
6	12	360	153.00	3.20
8	12	390	178.50	3.40
10	12	570	232.75	3.60

DIFFERENTIAL BLOCKS

Capacity in tons	Hoist in feet	Weight, lbs. (net)	Price	Extra hoist per ft.
1/8	5	11	$ 9.00	$1.40
1/4	6	22	9.00	1.40
1/2	7	30	10.50	1.40
1	8	51	14.00	1.50
1 1/2	8 1/2	81	18.00	1.60
2	9	122	22.50	1.70
3	9 1/2	180	30.00	2.00

Gages and Cocks. The following tables give prices of typical gages and cocks.

AIR COCKS

Size, ins.	Hexagon	Double ends	Bibb. nose
1/8	$0.15	$0.19	$0.25
1/4	.19	.23	.29
3/8	.23	.27	.34
1/2	.30	.38	.42

COMPRESSION GAUGE COCKS

Size, ins.	Price
1/4	$0.36
3/8	.41
1/2	.45
3/4	.50

The above cocks are soft seat and plain, for cocks with stuffing boxes 10 cts. is added to the above prices.

ASHTON IMPROVED HYDRAULIC GAUGE

Size of dial, ins.	Iron case and brass ring	Brass case
12	$44	$50
10	36	40
8 1/2	28	32
6 3/4	20	24
6	14	16
5	12	14

The above hydraulic gauges are for high pressures above 1,000 lbs.

COMBINED PRESSURE AND RECORDING GAUGE

Size of dial, ins.	Brass case	N. p. case
6 3/4	$28.00	$29.40
8 1/2	35.00	36.40
10	45.50	47.50
12	59.50	62.50

ASHTON IMPROVED PRESSURE GAUGE

Size of dial, ins.	Iron case, brass ring	Brass case
12	$17.50	$26.30
10	11.20	14.00
8 1/2	7.70	10.50
6 3/4	5.60	7.00
6	4.50	5.60
5 1/2	3.50	4.20
5	2.80	3.85

Prices include cocks.

Prices of vacuum gages in the above sizes are approximately the same as these for pressure gages.

ALTITUDE GAUGES

Size of dial, ins.	Iron case, brass ring	Brass case
12	$21.00	$28.00
10	14.00	17.50
8½	10.50	14.00
6¾	7.00	8.75
6	5.60	7.00
5½	4.90	5.60
4½ or 5	4.20	4.90

Prices include cocks.

WATER GAUGES

		Finished parts with rough body			All finished		
Glass, ins.	Pipe, ins.	Two rod	Three rod	Four rod	Two rod	Three rod	Four rod
½	⅜	$1.38	$1.75	...	...	...	...
⅝	½	1.50	2.00	$2.50	$1.88	$2.50	$3.25
¾	¾	3.00	4.00	4.25	4.00	4.75	5.00

Hose. The following are approximate prices for hose.

LINEN FIRE HOSE

Size, ins.	Net price per foot
¾	$0.11
1	.12
1¼	.14
1½	.15
1¾	.16
2	.17
2¼	.18
2½	.20
3	.28

The above sizes are for 500 lbs. pressure. For 550 lbs. pressure an increase of 1 ct. per foot is added on the first five sizes and 5 cts. per foot on the last four.

COTTON RUBBER LINED FIRE HOSE

Size, ins.	Net price per foot
1⅜	$0.32
1⅝	.35
2⅛	.40
2⅝	.45

Indicators. The following prices are for indicators.

Thompson Improved Indicator, for obtaining indicator diagrams or cards from steam engines cost with two springs about $50 each f.o.b. shipping point.

Thompson Improved Ammonia Indicator, made entirely of steel so that the action of ammonia will not affect the indicator, cost with two cocks, one spring, scales, wrenches, etc., $67.50 each f.o.b. shipping point.

Jacks. The following prices are for hydraulic jacks.

HYDRAULIC JACKS

Plain Jacks:

Tons lift	4	7	10	20	..	..
Run out, inches	12	18	24	18	..	..

Height, inches	24	32	39	33	..	..
Weight, pounds	50	75	110	155	..	..
Price, dollars	48	58	88	116	..	..
Broad Base Jacks:						
Tons lift	4	7	10	20	30	50
Run out, inches	12	18	18	18	18	12
Height, inches	25	31	31	32½	33	28
Diam. of base, inches	9½	10	12	13	13¼	15
Weight, pounds	65	97	130	206	260	320
Price, dollars	50	60	70	110	150	190
Screw Jacks:						
Number	1	4	8	13	17	..
Diam. of screw, inches	1¼	1½	1¾	2	2½	..
Height when down, in.	8	12	16	20	24	..
Net rise, inches	4	7	10	13	18	..
Whole height, in.	12	19	26	33	42	..
Est. lift cap., in.	5	8	12	15	20	..
Weight, pounds	9½	22	33	45	82	..
Price	$2	$3	$4	$6.40	$10.40	..

Lubricators. The following are approximate prices of lubricators.

GREASE CUPS, COMPRESSED AIR TYPE

Capacity, ounces	Polished	Plain
½	$0.60	$0.50
1	.80	.65
3	1.00	.75
6	1.25	.90

AUTOMATIC COMPRESSION TYPE GREASE CUP

Capacity, ounces	Shank pipe thread, ins.	Finished brass	Nickel plated
⅓	⅛	$0.45	$0.55
1	¼	.60	.70
1½	¼	.75	.85
3	⅜	1.00	1.10
6	½	1.30	1.50
10	½	1.80	2.00

SCREW FEED GREASE CUPS

Capacity, ounces	Shank pipe thread, ins.	Finished brass	Nickel plated
⅓	⅛	$0.45	$0.55
1	¼	.55	.60
1½	¼	.70	.80
3	⅜	.85	1.00
6	½	1.20	1.45
10	½	1.75	2.00

SNAP LEVER OIL CUP WITH SIGHT FEED

Capacity, ounces	Shank pipe thread, ins.	Finished brass	Nickel plated
⅝	⅛	$0.60	$0.70
1	¼	.65	.75
1½	¼	.70	.80
2½	⅜	.75	.85
4	⅜	.85	.95
5	⅜	1.10	1.15
10	½	1.45	1.60
18	½	1.85	2.00

AUTOMATIC LUBRICATORS, ROCHESTER TYPE, SINGLE FEED

Size in pints	Net price
½	$17.70
1	16.30
3	22.70
8	29.25

LUBRICATORS WITH TWO COMPARTMENTS

Size in pints		Net price
3	Double feed	$36.
8	Double feed	43
8	Triple feed	55
8	Quadruple feed	68

The above lubricators are for air compressors and ice machines, etc., where different kinds of oils are used in different cylinders of the same machines.

DUPLEX PISTON METERS FOR OIL

Size, ins.	Weight, lbs.	Net price
⅝	90	$38
¾	149	45
1	218	60
1½	230	66
2	280	77
3	590	165
4a	2,150	340
6a	5,400	830

The above prices are for meters with standard horizontal counter; for meters with special vertical counter $10 will be added to the given prices.

Lubricating Oils. Quotations continue without change, the following figures being named for 5-bbl. lots:

Neutral oils, filtered:

	Cents per gal.
* Cylinder, dark	20@27
* Cylinder steam, refined	14@22
Neutral oils, filtered:	
Stainless white, 32 to 34 gravity	28@29
Lemons, 33 to 34 gravity	17@19
Dark, 32 gravity	15@18
Crank case oil	15@17

* Prices are according to test.

Packing. Prices vary within wide limit, according to the brands of various dealers, but in general, packing can be purchased at the following quotations: Asbestos, wick and rope, 13 cts. per lb.; sheet rubber, 11 to 13 cts.; pure gum rubber, 40 to 45 cts.; red sheet packing, 40 to 50 cts.; cotton packing, 16 to 25 cts.; jute, 5 to 6 cts.; Russian packing, 9 to 10 cts.

Machine Tools. The following prices are for miscellaneous machine tools.

Lathes. Engine lathe, 24-in. swing, 12-ft. bed, compound rest, power cross feed, steady rest, two-face plates, friction countershaft, 2-in. hole through spindle and cabinet legs. This machine weighs

5,500 lbs. A second-hand machine of this kind can be bought for $375.

Engine Lathe: 25-in. swing, 12-ft. bed, compound rest, power cross feed, complete with countershaft and full equipment. Price, $375.

Engine lathe: 26-in. swing, 10-ft. bed, complete, $500.

Patented 2-in-1 double spindle lathe: 24-in.-40-in. Bed 12 ft. long, that turns 5 ft. between centers, triple geared, complete with countershaft and full regular equipment. This machine has back gears, hand and power feed, automatic stop, quick return, wheel and lever feed. Spindle is counterbalanced. The table has vertical adjustment on column by means of handle operating gear in rack. Shafts are made of steel. Gears are cut two to one and cone has four steps, 3$\frac{13}{16}$ ins. to 8$\frac{5}{16}$ ins. diameter. Price $970.

Quick change gear lathe: 14-in. swing, 6-ft. bed, takes between centers on bed 2 ft. 10 ins.; diameter of hole in spindle 1 in. and speed of countershaft, 130 r.p.m.; standard threads from 2 to 128, including 11½, and feeds from 7 to 450 per inch are obtained without the removal of a single gear. Provision is made, however, so that odd threads or feeds can be had with little trouble or expense. This lathe weighs packed for domestic shipment 1,600 lbs. and can be bought for $375.

Engine lathe: 18-in. swing, 10-ft. bed, with compound, steady and follow rests. One $\frac{9}{16}$-in. lathe through spindle, counter-shaft, etc. Also independent chuck 4-jaw; 16-in. reversible jaws to fit spindles of their lathe. Weight, 3,500 lbs. Cost, $643.

Hand feed tilted turret lathe: Plain head, oil pump and pan and automatic chuck and with lever or screw feed cut-off.

Automatic chuck capacity	¾ ins.	1 in.
Swing over bed	11 ins.	13 ins.
Maximum distance, end of spindle to face of turret	12 ins.	14 ins.
Counter shaft speed, r.p.m.	250	225
Shipping weight, lbs.	900	1,200
Net price	$300	$400

Drills. A new 20-in. upright drill, with back gears, power feed, quick return and automatic stop. This weighs 700 lbs. and the price net is $90.

Improved radial drill: Maximum height of drill when arm is up, 9 ft.; maximum radial distance, 60 ins.; vertical adjustment of arm on column, 26 ins.; receivers under spindle over base, 3½ ins.; smallest diameter of spindle, 1$\frac{9}{16}$ ins.; traverse of spindle, 10 ins.; floor space for base, 6¼ ft. × 28 ins.; speed of countershaft, 350 r.p.m.; net weight of machine, 2,850 lbs.; net price, $500.

Stationary head vertical drilling machine with geared power feed, automatic stop and back gears.

Size, ins	Weight, lbs.	Net price
21	1,300	$135
24	1,550	200

Sliding head drill press: 18 ins., with countershaft adjustable head and table. Height over all 7 ft. 5 ins., base plate 1 ft. 9 ins. by 4 ft. 6 ins. together with one table vice for this drill press, jaws open 7 ins., width 8⅝ ins., depth 2½ ins. Weight of press 1,600 lbs.; vice 180 lbs., cost $238.

Milling Machines. The following are costs of milling machines:

Type	Universal	Heavy plain
Table feed — automatic	20 ins.	24 ins.
Cross adjustment	7½ ins.	10 ins.
Vertical adjustment	17 ins.	19 ins.
Working surface of table	37 x 8½ ins.	48 x 11¼ ins.
Number of feed changes	16	16
Number of spindle speeds	8	16
Spindle speeds, r.p.m.	16½ to 404	12 to 384
Feed per rev. of spindle		
Speed of counter shaft pulleys,	.006 to .100 ins.	.005 to 268 ins.
r.p.m.	123 to 293	107 to 270
Domestic shipping weight, lbs.	2,500	3,700
Net price	$750	$650

Hand milling machine.

Adjustment of table outward from column	3¼ ins.
Total length of table feed	11 ins.
Vertical feed of knee	6 ins.
Greatest distance from center of spindle to top of table	6 ins.
Working surface of table	4 x 15 ins.
Number of grades on cone	3
Speed of countershaft, r.p.m.	200
Weight including arm, vise, vertical attachment and countershaft, lbs.	600
Net price without vertical attachment	$225
Net price with vertical attachment	$255

Miscellaneous Tools. A No. 2 standard bolt cutter, to thread bolts or tap nuts ⅜-in. to 1½-in. right or left hand, weighs 1,200 lbs. and can be bought second-hand for $175 net.

A single end-punch or shear weighs about 4,500 lbs. and will punch 1-in. hole through ½-in. plate or will shear 4-in. × ½-in. bars. A second-hand one will cost $300 net, while a new one would cost about $500.

A new 4-in. pipe machine for hand or power takes from 1-in. to 4-in. right or left, weighs 525 lbs. net or 650 lbs. gross, and can be bought for $170 net.

A new three-geared ball bearing Upright, self-feed blacksmith post drill weighs 240 lbs. and costs $18.50 net.

A new circular saw, with wood table, weighs about 300 lbs. and costs $50 net.

A new 30-in. band saw with iron table weighs about 850 lbs. and costs $100 net.

Grindstone, machinist's: 30-in., heavy, mounted on an iron frame, with shield and water bucket, weighs about 1,500 lbs. and costs new about $50.

Twenty-inch, back geared crank shaper: Automatic cross travel, 24 ins.; vertical adjustment of table, 15 ins.; size of tool, 1¼ by ⅝ in.; number of speeds to ram, 8; minimum number of strokes

per minute, 7; maximum number of strokes per minute, 105; number of feeds, 16; r.p.m. of crank shaft, 280; net price, $500.

Back geared crank shaper: Size 16 ins.; with vise for drill press, table support, telescope screw arranged for key seating, counter-shaft, etc., complete. Floor space, 2 ft. 1 in. by 3 ft. 10 ins. Cost, $300.

Pipe machine. Size, 2 ins. by 8 ins. with counter-shaft. Floor space, 2 ft. by 3 ft. Weight, 1,400 lbs. Either hand or power. Cost, $550.

Tool grinder with column, complete with counter-shaft and hand rest. Arranged for 2 wheels 12 ins. diam. by 2 ins. wide. Floor space 1 ft. 3 ins. by 1 ft. 10 ins. Cost, $28.

Metal power hack saw, with counter-shaft. Cost $126.

Power bolt cutter and nut tapper: Size, ¾ in. to 1½ ins., with counter-shaft, dies, etc.; floor space 2 ft. 5 ins. by 4 ft. 11 ins.; weight, 915 lbs.; cost, $132.

Wood boring machines: Capacity, 2-in. hole, reversible; size, B. W.; cost $70.

Band saw: Diameter of wheel, 36 ins.; table, 30 ins. by 32 ins.; 1-in. saw; floor space, 3 ft. 2 ins. by 4 ft. 8 ins.; cost, $150.

Wood frame, rip saw bench with counter-shaft and pulleys: Table, 3 ft. by 5 ft.; pulleys 5 ins. by 6 ins.; for saws 16-in. to 20-in. diameter, 1⅛-in. bore.; speed, 2.000 r.p.m.; 7½ to 15 h.p.; weight, 350 lbs.; equipped with wire hood, saw guard with improved knuckle joint to take 23-in. saw — together with 1 — 20-in., 1 — 17-in., 1 — 14½-in., 1 — 15-in. and 1 — 12-in. saw; cost, $121.50.

Steel screw punch: Capacity, 13/16-in. hole in ¾-in. plate; center of punch to back of gap, 2½ ins.; cost, $35.

Cost of Tool Operation in Engine Manufacturing. The following costs of machine-tool operations in steam-engine manufacturing, by Wm. O. Webber, appeared in the Engineering Magazine, Aug., 1910:

"Mr. Webber's cost data are gathered within recent years from his own experience in the management of machinery-building works in the eastern United States. Careful reconsideration of the figures, and comparison with like costs in other shops, shows that any improvement in tools since Mr. Webber's tables were compiled is about offset by rise in wages, so the data correctly represent average present performances."

Some results obtained experimentally in various classes of metal-cutting work are noted in the accompanying tables. The first of these tables shows machining costs on connecting rods for small, simple horizontal engines, where the work was done in lots of 20 parts each. Some interesting data were obtained as to the relative cost of forging and machining. For instance, these connecting rods were made largely from round iron with ends upset to form the rectangular parts to which the brasses and straps were attached, the rods being then turned a double taper from the center, reducing toward each end. Forging at the price given (which included the straps and keys for each size rod) left a surplus of stock to be turned off in the lathe between the square ends, or

TABLE I. COST OF VARIOUS MACHINE OPERATIONS ON STEAM ENGINES

COST OF MAKING CONNECTING RODS

Size of engine	Forging, per piece	Turning (each) 1 Lathe	Turning (each) 2 Lathes	Planing Fitting	Planing Finishing	Slotting straps, per pair	Planing straps, per pair	Turning brasses, per pair	Assembling per set of five
8 x 12	$1.15	$0.38	$0.26	$1.00	$1.30	$0.21	$0.25	$0.25	$8.50
9 x 12	1.25	0.40	0.27	1.15	1.85	0.21	0.25	0.25	9.00
10 x 12	1.35	0.40	0.27	1.15	1.85	0.23	0.30	0.27	9.80
10 x 15	1.45	0.45	0.32	1.30	2.20	0.26	0.30	0.27	11.20
11 x 15	1.60	0.50	0.35	1.30	2.20	0.27	0.33	0.30	12.25
12 x 16	2.00	0.55	0.36	1.50	2.50	0.44	0.35	0.33	13.80
14 x 16	2.40	0.60	0.42	1.75	2.75	0.50	0.35	0.60	15.50

COST OF MACHINE-TOOL LABOR IN BUILDING CENTER-CRANK ENGINES

Size	Lathe	Drill	Planer	Vise	Slotter	Shaper	Bolt cutter	Black-smith	Total hours	For one engine
8 x 12	$104.56	$31.44	$40.14	$240.57	$11.87	$14.20	$4.22	$29.25	2,405.00	$26.83
9 x 12	116.88	30.18	54.09	279.81	14.50	16.66	4.22	31.50	2,813.00	30.85
10 x 12	122.40	51.42	61.83	283.05	12.87	11.98	4.55	31.50	3,090.00	31.25
10 x 15	138.56	48.12	59.31	283.59	14.00	17.08	5.20	33.75	3,365.5	34.24
11 x 15	159.20	51.00	65.61	331.56	12.87	18.61	5.20	33.75	3,974.35	34.79
12 x 16	174.88	76.68	72.36	350.64	21.25	46.15	5.52	36	4,707.50	40.37
13 x 16	168.80	54.60	82.98	405.27	23.25	22.27	5.52	38.25	4,530.00	45.30
14 x 16	216.16	88.24	94.04	450.18	25.00	49.46	5.84	40.50	5,350.00	53.50

PERCENTAGES OF LABOR AND COSTS. CENTER-CRANK ENGINES

8 x 12	$21.90	$6.60	$8.45	$50.5	$2.48	$2.98	$0.88	$6.10–$99.89
10 x 12	21.00	8.90	10.70	48.7	2.21	2.06	0.78	5.42– 99.77
12 x 16	22.20	9.80	9.20	44.7	2.71	5.90	0.70	4.60– 99.81
Average	21.70	8.43	9.45	47.9	2.46	3.64	0.75	5.37– 99.76

This table shows the percentage of labor and costs for three different sizes of these engines, from which it will be seen that the percentages for the different classes of work are very uniform. This is also true of side crank engines of the same general type with hooded bed and overhung cylinders.

(in shop parlance) the "stub ends." It was therefore determined to forge the rods more closely to the finished size; but the saving in turning was more than made up in the extra cost of blacksmithing, lathe work costing only about 19 cts. an hour as against the cost of 45 cts. per hour for blacksmith, helper, and fire.

TABLE II. COSTS OF OPERATIONS ON CENTER-CRANK SHAFTS

Size	Turning (each) 1 Lathe	2 Lathes	3 Lathes	Turning discs.	Slotting discs.	Key seating
8 x 12	......$1.80	$1.15	$1.00	$0.35	$0.31	$0.20
9 x 12	...... 1.80	1.15	1.00	0.35	0.31	0.23
10 x 12	...... 2.00	1.40	1.23	0.40	0.33	0.24
10 x 15	...... 2.50	1.65	1.44	0.45	0.40	0.27
11 x 15	...... 2.60	1.70	1.49	0.50	0.40	0.30
12 x 16	...... 3.00	2.20	1.75	0.60	0.45	0.34
14 x 16	...... 3.15	2.40	2.00	0.70	0.50	0.38

TABLE III. TIMES OF OPERATIONS ON SHAFTS OF VARIOUS SIZES

Diameter of shaft, ins.	Number of hours for turning and key-seating shaft 1 ft. long.	Diameter of shaft, ins.	Number of hours for turning and key-seating shaft 1 ft. long.	Diameter of shaft, ins.	Rough weight of engine shaft per ft., in lbs.	Diameter of shaft, ins.	Rough weight of engine shaft per ft., in lbs.
2⅜	1.23	6½	2.98	2⅜	18.17	6	107.21
2⅝	1.33	7	3.22	2⅝	21.80	6½	124.71
2⅞	1.42	7½	3.42	2⅞	25.73	7	143.50
3⅜	1.62	8	3.51	3	27.87	7½	163.65
3½	1.66	8½	3.84	3⅜	34.67	8	185.05
3⅝	1.71	9	4.03	3½	37.10	8½	207.76
3⅞	1.80	9½	4.22	3⅝	39.61	9	231.89
4	1.85	10	4.41	3¾	42.19	9½	257.29
4¼	2.02	10½	4.59	3⅞	47.60	10	283.92
4⅜	2.07	11	4.78	4	50.40	10½	311.92
4½	2.12	12	5.16	4¼	56.44	11	341.43
4⅝	2.17	13	5.54	4⅜	59.53	12	404.04
4¾	2.23	14	5.90	4½	62.69	13	472.08
4⅞	2.29	15	6.29	4⅝	65.94	14	545.16
5⅛	2.37	16	6.67	4¾	69.28	15	631.68
5⅜	2.49	17	7.04	4⅞	72.68	16	715.68
5½	2.54	18	7.42	5⅛	79.80	17	806.40
6	2.80	..	...	5⅜	87.08	18	900.48
...	...	..	...	5½	91.05	..	.....

Some more interesting figures were obtained in different methods of doing the work, that is machining straps on the shaper as against doing the same work on a planer, and milling brasses on a milling machine, as against doing the same work on a shaper.

It will be noted also that there are two prices given for lathe work, the price for two lathes being cheaper than that for one lathe. In this latter case the workmen would rough out on the one lathe and finish on the second. This difference of price in connection with the use of more than one tool is emphasized in the turning of crank shafts for these same center-crank engines for instance.

TABLE IV. COSTS OF VARIOUS MACHINE OPERATIONS ON STEAM ENGINES

BEDS

Size of engine	Drilling Pillow blocks	Drilling Other holes	Planing	Babbetting and putting in studs
8 x 12	$0.12	$0.27	$0.50	$0.90
9 x 12	0.12	0.29	0.50	0.90
10 x 12	0.14	0.29	0.60	1.05
10 x 15	0.16	0.35	0.70	1.15
11 x 15	0.18	0.40	0.80	1.25
12 x 16	0.20	0.45	0.90	1.60

CYLINDERS

Size of engine	Boring 1 mch.	Boring 2 mch.	Planing	Vise work	Turning heads	Drilling
8 x 12	$0.76	$0.60	$0.50	$1.15	$0.22	$0.25
9 x 12	0.80	0.64	0.65	1.20	0.25	0.29
10 x 12	0.88	0.70	0.70	1.20	0.30	0.32
10 x 15	0.96	0.77	0.85	1.30	0.30	0.34
11 x 15	1.02	0.82	0.85	1.60	0.35	0.37
12 x 16	1.12	0.90	0.95	1.60	0.10	0.40
14 x 16	1.44	1.15	1.20	2.25	0.60	0.45

PISTONS

Size of engine	Turning	Drilling	Bolt cutter on rods	Rings, turning
8 x 12	$0.80	$0.12	$0.12	$0.13
9 x 12	0.88	0.15	0.15	0.14
10 x 12	1.00	0.20	0.20	0.15
10 x 15	1.00	0.20	0.20	0.15
11 x 15	1.20	0.20	0.20	0.16
12 x 16	1.25	0.25	0.25	0.17
14 x 16	1.50	0.30	0.30	0.19

SLIDES

Size	Planing top	Drilling
8 x 12	$0.00	$0.07
9 x 12	0.40	0.07
10 x 12	0.40	0.07
10 x 15	0.45	0.07
11 x 15	0.55	0.07
12 x 16	0.70	0.08
14 x 16	1.00	0.10

STEAM CHEST COVERS

Size	Planing	Milling
8 x 12	$0.27	$0.15
9 x 12	0.30	0.17
10 x 12	0.30	0.20
10 x 15	0.32	0.22
11 x 15	0.35	0.25
12 x 16	0.40	0.25
14 x 16	0.50	0.30

In roughing out the workman could easily run two lathes or in finishing it paid him to hire an apprentice at a fixed rate to assist him in running the three lathes.

A large saving in cost was made by tapping the holes which had

TABLE V. TIME REQUIRED TO TURN, KEY-SEAT, AND BALANCE, PULLEYS, PER INCH WIDTH OF FACE

Allowance is made for pulleys in rough, hours and decimal parts of an hour

Diameter of pulley, ins.	Hours required to turn, balance and key-seat pulley 1 in. wide	Diameter of pulley, ins.	Hours required to turn, balance and key-seat pulley 1 in. wide	Diameter of pulley, ins.	Hours required to turn, balance and key-seat pulley 1-in. wide
6	.283	54	1.789	100	3.23
8	.346	56	1.852	102	3.29
10	.408	58	1.915	104	3.35
12	.471	60	1.977	106	3.41
14	.534	62	2.040	108	3.47
16	.585	64	2.100	110	3.54
18	.648	66	2.160	112	3.60
20	.711	68	2.220	114	3.66
22	.774	70	2.280	116	3.72
24	.836	72	2.350	118	3.80
26	.899	74	2.41	120	3.84
28	.962	76	2.47	122	3.90
30	1.026	78	2.54	124	3.96
32	1.083	80	2.60	126	4.00
34	1.151	82	2.68	128	4.06
36	1.213	84	2.72	130	4.12
38	1.276	86	2.79	132	4.18
40	1.339	88	2.85	134	4.25
42	1.402	90	2.91	136	4.31
44	1.465	92	2.98	138	4.37
46	1.528	94	3.00	140	4.43
48	1.590	96	3.00	142	4.49
50	1.663	98	3.16	144	4.54

TABLE VI. COSTS OF VARIOUS OPERATIONS ON STANDARD BOILERS; HAND WORK

Setting Flues

1½-inch and 2-inch flues .... 5 cents
3-inch flues .... 6 cents
3½-inch and 4-inch flues.......................... 8 cents
6-inch flues, ... 12 cents
Punching and reaming flue holes................30 cts. per hundred
Chipping edges of sheets of boilers..........4½ cts. per lineal foot
Caulking ....2 cts. per lineal foot
Punching rivet holes ....15 cts. per hundred
Riveting boilers with either steam or hydraulic rivets, 40 cts. per hundred rivets, an average day's work being about one thousand ¾-inch rivets.
Stay bolts, 3¾ cts. each for tapping, putting in, and driving.

to be threaded in the cylinders by machinery at the same time that the holes in the cylinders were being drilled; for instance, in a 10 by 12 cylinder there are sixteen holes which average ¾ in. and sixteen small holes for attaching the sections of the jacket to the cylinder. The price for drilling all of these holes was 32 cts.,

or 1 ct. per hole; which is very much cheaper than they could be tapped by hand afterwards.

It may seem a difficult thing to make piece work prices on painting, including the striping, of such things as engines, but for

Engines	18 x 12 to 10 x 12	the price was	$0.80,
	10 x 15 to 12 x 16	" " "	0.90,
	13 x 16 to 14 x 18	" " "	1.00, including varnishing.

These prices included varnishing also.

Machine Tools. Cutting Speed, Diameter of Cut, R.P.M., Length Finished per Minute. J. H. VanDeventer in Lefax gives the following data applicable to lathe and boring mill work, when the diameter of the cut and the desired cutting speed are known:

1 — The necessary r.p.m. to secure the cutting speed.

2 — The length of cut finished per min. with a given feed. The latter is of great value in estimating time required to finish a given job, or to check up time records to see if a reasonable duration has been exceeded.

By means of the double scales, A and B, diam. from 0.7 in. to 60 ins. are included in Fig. 1. The capacity of curves of reference may often be widely increased by shifting the decimal points in this manner, in the same way that the universal slide rule decimal point is shifted.

By doubling values on the scale of cutting speeds, this chart of curves may be used up to a cutting speed of 200 ft. per min., which is as high as will be used in ordinary shopwork. In this case, the values of the A and B scales, both horizontal and vertical, should be doubled.

Example 1 — What is the necessary r.p.m. for an 18-in. diam. to secure a cutting speed of 60 ft. per min.?

Find the 18-in. curve as denoted on scale A at the top of the chart, and run down this curve to the horizontal representing 60 ft. cutting speed. Then drop vertically to bottom of chart and read 12.7 r.p.m. on lower horizontal scale A.

Example 2 — In this case, with 12.7 r.p.m. and a feed of ⅛ in. per revolution, what distance will be finished per min.?

From 12.7 r.p.m. on horizontal scale A, run vertically to angular line representing ⅛-in. feed. From this intersection, run horizontally to right vertical scale A, and read 1.58 ins.

Example 3 — Given 40 ft. cutting speed, 2 ins. diameter of cut, 1/32 in. feed per revolution, what length will be finished per minute?

From 2 ins. diameter on scale B at top of chart, run down the angular curve representing this diameter until it intersects the horizontal representing 40 ft. per min. cutting speed. Then vertically until the angular line represent 1/32-in. feed is intersected and from this point horizontally to right vertical scale B, and read 2.4 ins.

The results obtained with these curves will be fully as accurate as slide rule results and obtained in one quarter the time.

Practical Cutting Speeds. For detailed experiments on roughing

cuts, see Taylor's Art of Cutting Metals. The following will serve as a guide to good modern practice using high speed steels.

	Cast iron per min.	Steel per min.	Brass per min.
Soft	60 to 100 ft.	80 to 150 ft.	150 to 200 ft.
Medium	40 to 60 ft.	60 to 80 ft.	80 to 150 ft.
Hard	20 to 40 ft.	35 to 60 ft.	40 to 80 ft.

Limits depend on the feed and depth of cut. Properly treated and ground tools should stand up at these speeds at least one hour between grindings. All tools should have the cutting edges rubbed with an oilstone after grinding, before putting in use.

Standard shapes, angles and hardening methods must be adopted if standard cutting speeds are to be insisted upon and obtained. Tools should be ground only by an expert, and dry wheels should be abolished.

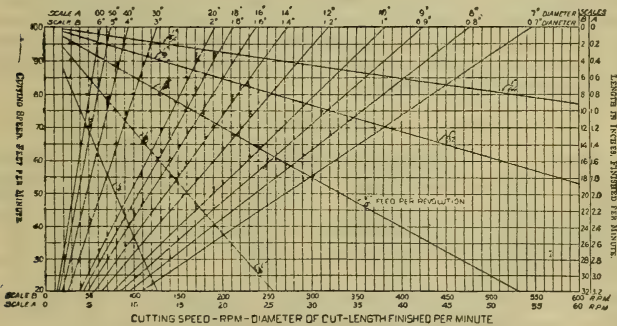


Fig. 1. Cutting speeds of machine tools.

Cutting Speed of High Speed Steel on Turret Lathes. H. I. Brackenbury (Engineering News, Aug. 18, 1910), states that on turret lathes the highest class of high-speed steel is now largely used, and tools with a very sharp cutting-angle are employed. A test, carried out at the works of Messrs. Alfred Herbert, gave the following result in reducing a mild-steel bar from 1½ ins. to ¾-in. diam. at one cut, with tool clearance angle 7 degs.; side slope 35 degs; cutting angle, 48 degs.

Tool	R.p.m.	Cutting speed, ft. per min.	Feed per rev.	Feed per min.	Lbs. removed per min.
Carbon steel	149	58.5	0.0134	2.01	0.753
Class C, special high-speed steel	470	185	0.05	23.5	8.8125

Cost of Tempering of Tools. The following from the Railway Electrical Engineer, Oct., 1915, gives some costs on tempering tools:

Dies. Reports from four different sources show it is the general practice on this road to purchase dies for a small diameter bolt, as a rule ½-in. size, and as they become worn they are softened, bored, rethreaded and retempered for use on ⅝-in. size bolts. They are again used until worn down so not fit for further use and again pass through the same process as before increasing them to the next larger size. These several processes are carried on until the stock of the dies is so much used up it is impossible to go through with another, which usually ends when the dies have been worked up to 1 in. or 1⅛ ins., thus the one die serves during its life for the several sizes if it is properly worked and handled.

Costs. The costs herein used are an average obtained from several different shops taken independently of each other and then compiled and although an average is used in no cases were the limits of high and low costs greater or less than 10% from each other; therefore, should be quite correct. It will also be understood that costs of air are based on an electric driven blower current costing two cents per kilowatt-hour and on such tools that will require more than one heat to work them this is taken into account per unit price each.

DIES

Size	Softening	Labor to increase size	Retempering	Total
½ in. to ⅝ in.	$0.0383	$0.10	$0.041	$.1793
⅝ in. to ¾ in.	.0378	.112	.04	.1898
¾ in. to ⅞ in.	.0371	.121	.04	.1981
⅞ in. to 1 in.	.0365	.142	.038	.2165
1 in. to 1⅛ ins.	.031	.161	.038	.23
1⅛ in. to 1¼ ins.	.031	.164	.038	.233

In making these figures, machinists' labor costs at 40 cts. per hr. were used and the blacksmiths' labor at 39 cts. per hr.

TAPS

Size	Softening	Labor of dressing	Retempering	Total
1⅛ in. to 1 in.	$0.0423	$0.123	$0.0542	$0.2195
1 in to ¾ in.	.041	.119	.0540	.214

REAMERS

Nothing obtainable on this.

MACHINE TOOLS

Size	Labor of dressing	Tempering	Total
Small	$0.0633	$0.043	$0.1073
Large	.0825	.052	.1345

Very little information was obtainable on these.

CHISELS

Size	Labor of dressing	Tempering	Total
Small	$0.041	$0.032	$0.073
Large	.063	.052	.104

The last two items are usually of the best steel and it is necessary often to make more than one heat to work them. Some of the costs collected under the head of "Chisels" are considerably higher than here given.

Cost of Tools and Equipment in the Shops of an Electric Railroad. The following costs of tools and equipment were taken from an appraisal by the authors in 1912:

MACHINE SHOP TOOLS

1 Pease planter 24 in. by 6 ft. stroke complete with countershaft	$ 250
1 Forsyth lathe with countershaft, 24 in.	750
1 20 in. Forsyth lathe with countershaft	450
1 26 in. American lathe with countershaft	1,200
1 24 in. American lathe	1,200
2 air compressors 12 in. by 14 in., G. S. D. (made by Chicago Pneumatic Co.) complete with 2 36 in. by 8 ft. air tanks piping and 2 air gauges	1,800
1 National brake and elec. air compressor, type V. S. 90, 225 cu. ft. No. 118 A complete with induction motor, 40 h.p., 2 phase 95-4/10 amps., 200 volt with air tank 5 ins. diam., 11 ft. 10 in. long piping	2,150
1 two-ton Sprague electric hoist	433
4 10-screw car hoists (Hefferman Machine Works, Seattle, Wash.), equipped with G. E. 1,200 motor and A 2 controller	7,000
8 wooden horses with iron roller used for handling rail on bulldozer	64
1 250 lb. steam hammer	405
1 1,100 lb. steam hammer (made by Bement Niles Co.)	1,500
1 National bolt cutting machine complete with counter shaft and dies	500
1 Q. and C. rail cut off machine with counter shaft and two saws, also 66 Faber cut off saw teeth. Complete 40 Faber saw teeth. Wedges Faber saw teeth, yokes with set screws	1,500
1 G. E. 7½ h.p. induction motor, 10 amps., 220 volt	130
1 G. E. 20 h.p. induction motor, 44 amps., 220 volt	292
1 G. E. 25 h.p. induction motor, 56 amps., 220 volt	290
1 G. E. 25 h.p. induction motor, 61 amps., 220 volt	290
1 Beauford 48 in. boring mill with No. 27 Midvale self hardening steel tools	1,200
1 22-in. Barns drill press	75
2 20-in. Barns drill press	150
1 24-in. Aurora drill press	75
1 48-in. American radial drill press with countershaft	1,400
1 26-in. back gear drill press	75
1 Baudry automatic belt hammer	150
1 American twist drill grinder with one emery wheel and 1 carborundum wheel	65
1 derrick with 12 in. by 12 in. wooden mast and 12 in. by 12 in. wooden boom 60 ft. long equipped with hoist manufactured by Am. Hoist and Derrick Co., St. Paul	1,800
5 steel jib swing cranes	150
4 steel jib wall cranes	120
2 wooden jib swing cranes	20
1 steel jib swing crane	75
1 car wheel hoist crane	25
1 32-in. stroke complete with countershaft fiber pulley 8 in. diam., 4 in. face Cincinnati shaper machine	800
Midvale self-hardening steel tools No. 38	30
1 Septol shaper 24 in. stroke complete with countershaft	250
1 Niles Bement car wheel lathe complete with G. E. motor class C. 20 form B. 25 h.p., 500 volt, 43 amps., constant current	6,000

Midvale self-hardening steel tool No. 120	$ 96
1 18 in. American lathe with countershaft	750
1 stamping machine with 60 assorted punches and dies for blocking, breaking and drilling controller parts	700
1 Highey rail cutoff saw machine complete with G. E. induction motor, 10 h.p. 23 amps., 220 volt, and 2-30-in. Disston saws	1,500
1 Ajax bulldozer machine with 16 steel dies for bending rails	1,400
1 track grinder machine with 1 2-in. by 12-in. carborundum wheel and 1 3-in. by 12-in. wheel	250
1 machine for grinding switch tongue with 1 2-in. by 20-in. carborundum wheel	150
2 hand power shearing machines	20
1 Doty power punch and shear combined No. 17 G	1,000
1 Radial drill press with countershaft, No. 2 Bickford	700
1 150-ton capacity Shafter hydraulic wheel press	750
1 small hydraulic press with 7-in. plunger	200
1 Putnam 30-in. planer 8 ft. stroke complete with counter shaft	2,700
1 Cincinnati 42-in. planer 14 ft. stroke complete with countershaft	4,000
Wheel grinder machine complete with countershaft 2 carborundum wheels 2½ by 18 in.	350
Westinghouse d.c. motor 2½ h.p. 5 3/10 in. amps	60
G. E. induction motor 7½ a.j.p. 19 amps. 220 volt	130
G. E. continuous current motor, open 15 h.p. closed 7 h.p., open 25½ amps., closed 13 amps.	240
G. E. continuous current motor, 3 h.p., 5 43/100 amps., 500 volt	60
G. E. shunt wound 5 h.p. motor 9 amps., 500 volt	65
2 G. E. induction motors 60 h.p., 14 amps., 2,080 volt	1,362
G. E. induction motor 7½ h.p., 15 1/91 amps., 220 volt	130
G. E. induction motor 7½ h.p., 18 amps. 220 volt	130

WOODWORKING MACHINERY IN CARPENTER SHOP

1 J. A. Day tennoning machine, estimated value	$ 150
1 54-in. Royal invincible sanding machine (2nd hand cost $700)	700
1 Foley band saw filing machine, value	45
1 Eagon mortising machine	250
1 double emery stand Northampton	45
1 pattern lathe Eagon, 10-in. swing	65
1 Oliver bench saw and trimming machine, cost about	350
1 24-in. pony planer Eagon	450
1 band saw 36-in. Crescent Mfg. Co.	75
1 wood 36-in. band saw	200
1 Cordsman saw bench	75
1 Eagon 8-in. jointer	150
1 Williamsport 4 sided 6-in. sticker	105
1 Greenle rip saw, value	300
1 American swing cut off saw	75
80 ft. 2½ in. shafting, 12 pulleys	300
1 American 4 sided 7-in. sticker	150
50 ft. 2-in. shafting, 10 pulleys	200
1 25 h.p., 2 phase 200 volt, shop meter	275
2 500 volt, 3 h.p., fan motor	120
1 Standard sewing machine	35
3 Wilcox bench vises	15
1 steam glue pot	15

ELECTRIC REPAIR SHOP TOOLS

1 12-in. W. P. Davis speed lathe	$ 50
1 24-in. Armature banding lathe	175
1 24-in. Commutator grooving lathe	200
1 32-in. Peck, Stow & Wilcox cutting machine	40
1 double head emery stand	15

1 3-in. bench vise	$ 10
1 5-in. bench vise	10
2 6-in. bench vises	10
2 Field winding machines	150
2 armature coil taping machines	150
1 one ton electric hoist and carriage, Sprague Co.	475

Cost of Equipment for a Boiler and Blacksmith Shop. E. H. Jones (Bulletin of American Institute of Mining Engineers, July 1914) in describing the equipment of the boiler and machine shops of the Arizona Copper Co. of Clifton, Ariz., gives the purchase price of tools and the labor required to install them as follows:

	Factory	Freight	Total
1 No. 2 punch and shear (Hilles & Jones)	$1,530	$435	$1,965.00
1 No. 0 bending rolls	580	75	655.00
One 1,100-lb. steam hammer (Niles-Bement-Pond Co.) 1 blower, size 5, type D (American Blower Co.)	1,015	408	1,423.00
One 5-h.p. 440-volt, 3-phase, 60-cycle 1,720 r.p.m. motor	160	19	179.90
1 No. 5 swage block	....	...	35.08
1 Peter Wright anvil, weight 497 lb.	....	...	70.57
10 in. galv. iron pipe and connections	....	...	106.63
3 sheets steel, 1/8 in. by 48 ins. by 120 ins.	....	...	16.02
One 2-in. heading, upsetting and forging machine, (Acme Machinery Co.)	2,790	440	3,230.70
1 sisco anvil, 407 lb.	....	...	46.60
1 (Hay Budden) anvil, 420 lb.	....	...	48.10
40 ft. of 6-in. I-beam	....	...	12.62
Castings	....	...	41.00
Miscellaneous	....	...	29.14
			$7,859.36

Cost of Equipment for a Smelter Plant Machine and Blacksmith Shop. In describing the equipment of the machine shops of the Arizona Copper Co. of Clifton, Ariz., Mr. Jones gives the purchase price of material and the labor cost of installing as follows:

	Cost installed
1 (Prentiss) machine bench vise, No. 2	$20.15
1 machine bench vise, No. 21	20.16
1 machine bench vise, No. 22	28.85
1 machine pipe vise, No. 2A	2.38
1 machine pipe vise, No. 4A	7.77
1 stationary bench vise, No. 56	20.72
40 ft. of 1½-in. pipe	2.97
1 No. 48 power grindstone	56.62
2 emery wheels	8.90
1 emery wheel grinder	17.00
1 No. 40 special turning machine	36.22
1 set faces for wiring machine	5.56
1 gauge	2.35
1 burr machine and stand	9.92
1 No. 17 S. P. crimper and stand	10.77
1 No. 3 beading machine	26.79
1 No. 0236 squaring shears	180.86
1 stake-holder and stakes	42.15
1 rivet set	2.65
1 No. 101 tinner's rule	2.73
1 power hack saw No. 3	29.63

	Cost installed
1 radial drill press, 42 ins.	$752.20
Miscellaneous	21.92
1 50-in. cornice brake	155.96
1 16-in. rip saw	4.30
Castings	10.10
1 No. 1 drill chuck	5.61
1 No. 2½ drill chuck	7.02
72 hack saw blades	5.55

	Factory	Freight	Cost installed
1 surfacer, 20 in. by 6 in.	$180.00	$26.70	$206.70
1 No. 50 hand saw	175.00	27.45	202.45
1 lathe, 14 in. by 8 ft.	563.75	81.40	645.15
1 lathe (McCabe) patented double spindle	2,111.00	277.15	2,388.15
1 Crescent saw table	168.75	51.34	220.09
One 20-in. (Rockford) shaper	425.00	175.07	600.07
One 2-in. bolt cutter	355.00	47.10	402.10
1 (Crane) pipe machine 2 in.	192.00	16.56	208.56
1 (Crane) pipe machine 4 in.	480.00	44.10	524.10
1 (Crane) pipe machine 12 in.	1,500.00	163.59	1,663.59
Small tools, miscellaneous equipment	.....	.....	394.36
Total cost of all equipment	.....	.....	$8,953.13

Cost of Brass, Iron and Lead Pipe. The following costs are for various kinds of pipe.

SEAMLESS BRASS PIPE

	Common		Extra heavy	
Size in ins.	Weight per ft, lbs.	Net price	Weight per ft. lbs.	Net price
⅛	.25	$0.080	.370	$0.12
¼	.43	.136	.625	.20
⅜	.63	.168	.830	.22
½	.90	.228	1.200	.30
¾	1.25	.300	1.66	.40
1	1.70	.408	2.36	.56
1¼	2.50	.600	3.30	.80
1½	3.00	.720	4.25	1.02
2	4.00	.960	5.46	1.30
2½	5.75	1.380	8.30	2.00
3	8.30	1.990	11.20	2.68
3½	10.90	2.730	13.70	3.42
4	12.70	3.300	16.50	4.30
4½	13.90	3.890	19.47	5.45
5	15.75	4.750	22.80	6.85
6	18.31	5.65	32.00	9.90

WROUGHT IRON BLACK PIPE

Size, ins.	Weight per ft., lbs.	Price per ft.	Price for cutting	Price for cutting and threading
⅛	.244	$0.0165	$0.02	$0.03
¼	.424	.0180	.02	.03
⅜	.567	.018	.02	.03
½	.850	.0255	.02	.03
¾	1.130	.0287	.02	.03
1	1.678	.0425	.02	.03
1¼	2.272	.0575	.03	.04
1½	2.717	.0670	.04	.05
2	3.652	.085	.05	.07
2½	5.792	.135	.07	.10

Size, ins.	Weight per ft., lbs.	Price per ft.	Price for cutting	Price for cutting and threading
3	7.575	.176	.10	$.15
3½	9.109	.211	.13	.20
4	10.790	.262	.13	.20
4½	12.538	.305	.17	.25
5	14.617	.355	.20	.30
6	18.974	.418	.27	.40
7	23.544	.642	.33	.50
8	28.554	.778	.40	.60
9	33.904	.930	.67	1.00
10	40.483	1.110	.83	1.25
11	45.557	1.250	...	...
12	49.562	1.370	1.17	1.75
13	54.568	1.510	...	...
14	58.573	1.650	...	...
15	62.579	1.750	...	...

Prices per ft. for galvanized wrought iron pipe are 10% more than those given above.

EXTRA STRONG WROUGHT IRON PIPE

Size, ins.	Weight per ft., lbs.	Net price per ft.
⅛	.314	$0.0565
¼	.535	.0353
⅜	.738	.0353
½	1.087	.0517
¾	1.473	.0480
1	2.171	.0705
1¼	2.996	.096
1½	3.631	.117
2	5.022	.142
2½	7.661	.216
3	10.252	.288
3½	12.505	.350
4	14.983	.555
4½	17.611	.665
5	20.778	.770
6	28.573	1.070
7	38.048	1.410
8	43.388	1.610

SPIRAL RIVETED PIPE

Diameter, ins.	Thickness * Birmingham wire gage	Net price per 100 ft. With bolted joints complete		
		Plain	Ashphalted	Galvanized
4	18	$19.76	$21.48	$30.74
5	18	23.40	23.70	37.14
6	16	33.05	35.76	49.73
7	16	37.58	40.76	56.82
8	16	43.17	46.80	65.00
9	16	50.06	50.10	74.22
10	14	66.42	71.08	96.15
11	14	71.20	76.57	102.24
12	14	83.75	89.15	118.30
13	14	89.67	96.55	127.98
14	14	99.14	105.51	138.85
15	14	108.05	114.89	151.92
16	14	117.53	124.82	166.58
18	12	167.43	175.95	226.44

* Made in both lighter and heavier gages at corresponding differences in price.

Diameter, ins.	Thickness Birmingham wire gage	Net price per 100 ft. With bolted joints complete: Plain	Ashphalted	Galvanized
20	12	$183.79	$193.30	$248.39
22	12	200.48	210.64	269.21
24	12	219.92	231.07	293.99
26	10	280.20	292.41	370.78
28	10	301.32	314.89	395.37
30	10	324.81	399.15	430.64

The quotations are f.o.b. factory, freight equalized with New York, being figured at a discount of 50, 10 and 10% from list. These are for orders amounting to approximately $250. For large orders, prices are cheaper by 12½ to 20%.

Destination	Size, ins.: 4 and 6	4 and larger	4	6 to 12	Over 12
New York	....	$20 to $21	...	...	...
Chicago	....	....	$26	$24	$23
Birmingham	$19.50	....	...	...	...

The above are net prices per ton.
Gas pipe is $1 per ton higher in all.

LEAD PIPE

Size ins.	Weight per foot, lbs.	Size ins.	Weight per foot, lbs.
⅜ A	1¼	1¼ A	4¾
⅜ B	1	1¼ B	3¾
⅜ C	¾	1¼ C	3
½ A	1¾	1½ A	6½
½ B	1¼	1½ B	5
½ C	1	1½ C	4¼
⅝ A	2½	2 A	8
⅝ B	2	2 B	7
⅝ C	1½	2 C	6
¾ A	3	3 A	13
¾ B	2¼	3 B	9
¾ C	1¾	3½ A	15
1 A	4	3½ B	10
1 B	3¼	4 B	13
1 C	2½	4 C	8

A = Strong. B = Medium. C = Light.

Net price for lead pipe under normal conditions to jobbers and large consumers is 5.75 cts. per lb. and to small consumers 6.4 cts. per lb.

"STANDARD" CAST IRON FLANGED FITTINGS

Size, ins.	Tee	Cross	Elbow
2	$1.60	$2.20	$1.10
2½	1.70	2.40	1.15
3	1.90	2.60	1.30
3½	2.20	2.90	1.50
4	2.50	3.30	1.70
4½	2.80	3.80	2.00
5	3.20	4.40	2.25
6	4.10	5.70	2.90
7	5.30	7.30	3.80

Size, ins.	Tee	Cross	Elbow
8	$6.80	$9.20	$4.80
9	8.40	11.50	6.00
10	10.00	14.00	7.20
12	10.50	21.00	10.50
14	20.00	29.00	14.00
15	23.00	33.00	16.00
16	27.00	38.00	19.00
18	35.00	49.00	23.00
20	43.00	62.00	29.00
24	64.00	92.00	42.00

Forty-five degree bends cost about the same as elbows and Y's about the same as crosses.

The above fittings are for pressures up to 125 lbs. per sq. in.

COST OF DRILLING PER "STANDARD" CAST IRON FITTING

Size, ins.	Tee	Elbow	Cross
2	$0.39	$0.26	$0.52
2½	.46	.33	.65
3	.46	.33	.65
3½	.46	.33	.65
4	.75	.52	1.04
4½	.75	.52	1.04
5	.75	.52	1.04
6	.75	.52	1.04
7	1.50	.98	1.95
8	1.50	.98	1.95
9	1.55	1.04	2.10
10	1.55	1.04	2.10
12	2.35	1.56	3.10
14	2.85	1.80	3.65
15	3.10	2.10	4.15
16	3.40	2.35	4.75

Net cost for drilling 45 deg. bends. is the same as for elbows and Y's about the same as crosses.

"STANDARD" CAST IRON COMPANION FLANGES

Size, ins.	Faced	Faced and drilled
1 x 4	$0.26	$0.32
1¼ x 4½	.27	.35
1½ x 5	.29	.37
2 x 6	.32	.39
2½ x 7	.37	.52
3 x 7½	.42	.59
3½ x 8½	.47	.65
4 x 9	.56	.78
4½ x 9¼	.65	.87
5 x 10	.73	.95
6 x 11	.83	1.04
7 x 12½	1.15	1.50
8 x 13½	1.30	1.70
9 x 15	1.75	2.15
10 x 16	2.00	2.40
12 x 19	2.70	3.25
14 x 21	3.70	4.15
15 x 21	4.70	5.45
15 x 22¼	4.70	5.45
16 x 23½	5.80	6.80
18 x 25	7.15	8.15
20 x 27½	7.80	8.85
22 x 29½	8.80	10.00
24 x 32	10.60	12.00

"EXTRA HEAVY" CAST IRON FLANGED FITTINGS

Size, ins.	Tee	Cross	Elbow
2	$2.45	$3.25	$1.65
2½	2.65	3.50	1.80
3	3.00	4.00	2.00
3½	3.30	4.50	2.25
4	3.80	5.20	2.55
4½	4.40	6.00	2.90
5	5.00	6.80	3.30
6	6.40	8.80	4.30
7	8.25	11.50	5.60
8	10.50	14.50	7.00
9	13.00	18.00	10.00
10	16.00	22.00	11.00
12	23.00	31.00	16.00
14	32.00	43.00	22.00
15	37.00	50.00	26.00
16	42.50	57.00	30.00
18	55.00	72.00	38.00
20	68.00	90.00	47.00
24	100.00	....	70.00

Forty-five deg. bends cost about the same as elbows for all sizes over 5 ins.; the smaller sizes, however, cost about 8% more than prices given above. Y fittings are about the same as those for crosses.

The above fittings are for pressures up to 250 lbs. per sq. in.

COST OF DRILLING PER "EXTRA HEAVY" CAST IRON FITTING

Size in ins.	Tee	Cross	Elbow
2	$.61	$.81	$.40
2½	.71	1.00	.50
3	.71	1.00	.50
3½	.71	1.00	.50
4	1.20	1.62	.81
4½	1.20	1.62	.81
5	1.20	1.62	.81
6	1.20	1.62	.81
7	2.30	3.05	1.52
8	2.30	3.05	1.52
9	2.40	3.25	1.62
10	2.40	3.25	1.62
12	3.65	4.85	1.45
14	4.45	5.70	1.85
15	4.85	6.50	3.25
16	5.25	7.30	3.65
18	6.10	8.10	4.00
20	8.10	10.50	5.25
24	12.25	16.20	8.10

Net cost for drilling 45 deg. bends are the same as for elbows and Y's about the same as for crosses.

"EXTRA HEAVY" CAST IRON COMPANION FLANGES

Size, ins.	Faced	Faced and drilled
1 x 4½	$0.40	$0.50
1¼ x 5	.42	.54
1½ x 6	.44	.56
2 x 6½	.48	.60
2½ x 7½	.56	.80
3 x 8¼	.64	.90
3½ x 9	.72	1.00

Size, ins.	Faced	Faced and drilled
4 x 10	$.86	$1.20
4½ x 10½	1.00	1.32
5 x 11	1.12	1.46
6 x 12½	1.28	1.60
7 x 14	1.74	2.30
8 x 15	2.00	2.60
9 x 16¼	2.70	3.30
10 x 17½	3.10	3.70
12 x 20	4.20	5.00
14 x 22½	5.50	6.40
15 x 23½	7.20	8.40
16 x 25	9.00	10.40
18 x 27	11.00	12.40
20 x 29½	12.00	13.60
22 x 31½	13.60	15.60
24 x 34¼	16.40	18.40

Wood Stave Pipe. Key to table of dimensions and prices given in Table V.

A — Machine banded fir stave pipe, f.o.b. ships tackle, Portland or Seattle. Pipe packed and crated for export.

B — Pipe made of Oregons or Douglas fir, with 1½ in. shell. Lengths of pipe from 8 to 16 ft., with not more than 10% less than 10 ft. Inserted joint couplings made of the pipe (slip joint), one end of pipe being trimmed off for 3 ins., forming a tenon, the other end to be reamed to receive tenon. The wire gauge used to be W.-M. Standard, No. 4 being 0.225 and No. 2 being 0.263 ins. in diameter. (B 1) — Wood sleeve coupling to be of same class of material as the pipe sections, and not less than 6 ins. in length. No sap wood allowed in couplings. Couplings to be spirally wound with wire having a spacing not greater than one-half of spacing of wire on pipe. (B 2) — Individual band coupling to be made of staves and in same manner as wood sleep coupling, except that individual bands of round mild steel of size designated shall be used for the banding. Each band to be headed and threaded and supplied with nut and washer, and a malleable cast iron or drop forged shoe to be used in clinching the bands. The wire used shall be galvanized and have a strength of not less than 60,000 lbs. per sq. in. The prices given are f. o. b. cars, Portland, Ore.

C — Fir pipe of 1½ in. staves, with 8 in. sleeve couplings, each with three individual ½ in. round mild steel bands.

D — Similar pipe to C, but with steel adjustable clamp couplings. Weight per foot approximately the same as C.

E — Similar to C but with ½ in. bands (spaced as shown in table) instead of spirally wound wire and shipped "knocked down." The weight of the lumber used would be about 2,200 lbs. per thousand board feet of lumber, and the weight of the bands per thousand lineal feet of pipe as shown in the table.

F — Pipe similar to E but with steel couplings similar to those used in D. The prices of pipe under C, D, E and F are given f.o.b. cars, dock, Tacoma.

G — Redwood pipe, machine banded, built in sections of random lengths of from 8 to 20 ft. Wire having tensile strength of 60,000 to 65,000 lbs. per sq. in, shall be spaced with a safety factor of 4.

TABLE V. DIMENSIONS AND PRICES OF WOOD STAVE PIPE

		A		B			C			D	
Size, ins.	Head, ft.	Price per ft.	Outside diam., including crating, ins.	Price per ft.	Weight per ft. (lbs.)	Wire gauge and spacing	Outside diam. of pipe and coupling (ins.)	Price per ft.	Weight per ft. (lbs.)	Wire gauge and spacing	Price per ft.
12	25	$0.44¾	17	(B 1)		No. 4 Ga.				No. 2 Ga.	
	50	0.45¾		$0.33½	17.8	3 ins.	Pi. 15				
	75	0.46¾									
	100	0.48¼		0.37¾	19.1	1 13/16 ins.	Co. 17	$0.42	21	2½ ins.	$0.50
14	25	0.52	19	(B 2)		No. 4 Ga.				No. 2 Ga.	
	50	0.54¾		0.38½	20.7	3 ins.	Pi. 17				
	75	0.56½									
	100	0.59½		0.46¾	23.0	1 9/16 ins.	Co. 19¼	0.51	24	2⅛ ins.	0.60
16	25	0.61	21	(B 2)		No. 2 Ga.				No. 2 Ga.	
	50	0.62½		0.48	24.4	3 ins.	Pi. 19				
	75	0.64¼									
	100	0.68⅜		0.55¾	26.6	1⅞ ins.	Co. 21¼	0.59	27	1⅞ ins.	0.69
18	25	0.69⅛	23	(B 2)		No. 2 Ga.				No. 2 Ga.	
	50	0.71⅞		0.53½	27.2	3 ins.	Pi. 21				
	75	0.74½									
	100	0.80⅜		0.65¾	30.8	1⅝ ins.	Co. 23½	0.69	31	1⅝ ins.	0.80
20	25	0.76⅛	25	(B 2)		No. 2 Ga.				No. 2 Ga.	
	50	0.79⅛		0.57½	29.9	3 ins.	Pi. 23				
	75	0.82¾									
	100	0.90⅝		0.71¾	34.5	1½ ins.	Co. 25½	0.79	36	1½ ins.	0.91

TABLE V.— *Continued*

		E		F		G			H		
Size, ins.	Head, ft.	Price per ft.	Band size, and space (ins.)	Weight of bands per M ft. (lbs.)	Price per ft.	Price per ft.	Weight per ft. (lbs.)	Cub. contents (cu. ft.)	Price per ft.	Weight of staves per l. f. (lbs.)	Weight of bands per l. f. (lbs.)	Cubic contents staves (cu. ft.)
12	25		½									
	50											
	75											
	100	$0.48½	10	3,100	$0.54½	$0.55	16	1.5	$0.72	14	4	0.8
14	25		½									
	50											
	75											
	100	0.54	9¾	3,670	0.62	0.67	20	2.0	0.81	15	5	0.9
16	25		½									
	50											
	75											
	100	0.60	8½	5,000	0.70	0.78	24	2.5	0.90	16	6	1.0
18	25		½									
	50											
	75											
	100	0.68	7½	6,250	0.80	0.92	28	3.0	1.03	18	8	1.2
20	25		½									
	50											
	75											
	100	0.77	6¾	7,420	0.91	1.06	32	3.5	1.16	20	10	1.4

The staves shall be beveled and further provided with a small tongue and groove. Price f.o.b., dock, San Francisco.

H— Continuous redwood stave pipe, shipped "knocked down." Lengths of staves to be from 10 to 20 ft. with about 30% of 12 ft. stock. Ends of staves to have metallic tongues made from 1½ × ⅛ in. band iron. Bands spaced with a factor of safety of 4, to be round mild steel with malleable iron shoes. The rods to have a tensile strength of 58,000 to 65,000 lbs. per sq. in. Prices f.o.b. dock, San Francisco, Cal.

Cost of Wood Pipe on Pacific Coast. Table VI gives the cost of wood pipe on the Pacific Coast in 1912.

TABLE VI. COST OF WOOD PIPE

Size, ins.	Head in ft.	Spacing, ins.	Wire, No.	Shell, ins.	Price per ft.	Approx. wt., per ft.-lbs.
18	50	3	2	1¼	$0.83⅓	27.2
	100	1 15/16	1	"	.97	30.5
	150	1¼	1	"	1.12½	35.2
	200	1 15/16	1	1⅜	1.32	41.6
	250	¾	1	"	1.45½	45.1
	300	⅝	1	"	1.59½	49.2
	350	9/16	1	1½	1.71	54.2
	400	½	1	"	1.81½	57.2
16	50	3	2	1¼	0.73⅔	24.3
	100	1⅞	2	"	.83	26.5
	150	1 7/16	1	"	.92	29.4
	200	1 1/16	1	1⅜	1.13	35.3
	250	⅞	1	"	1.23	37.8
	300	1 11/16	1	"	1.37⅓	42
	350	⅝	1	1½	1.48	46
	400	9/16	1	"	1.57¼	50
14	50	3	4	1¼	0.59¼	20.6
	100	1 9/16	4	"	.69¼	22.8
	150	1 7/16	2	"	.76¼	25
	200	1	2	"	.89¾	28.5
	250	⅞	2	"	.97	30.1
	300	¾	2	1⅜	1.09⅔	33.8
12	50	3	4	1⅛	0.46⅔	16.2
	100	1 13/16	4	1⅛	.52	17.5
	150	1 3/16	4	"	.58¾	19.4
	200	1¼	2	1¼	.64⅔	22.8
	250	1	2	"	.70½	24.5
	300	1 3/16	2	"	.76¾	26.4
10	150	1 7/16	4	1⅛	.046½	15.7
	175	1¼	4	"	.48¾	16.25
	200	1 1/16	4	"	.52¼	17.1
8	150	1 13/16	4	"	0.35	12.4
	175	1 9/16	4	"	.36¼	12.8
	200	1 5/16	4	"	.38¼	13.3
6	150	2 7/16	4	"	0.25½	9.2
	175	2	4	"	.26⅔	9.5
	200	1 13/16	4	"	.27¼	9.7
4	175	2	4	1⅛	.19⅓	6.4
	150	2¼	4	"	.16⅓	6.0
	200	1¾	4	"	.19½	6.6

The 14–18 in. sizes are banded, the 16–12 in. sizes coupled and the 4 in. size has an inserted jointed wood sleeve.

Rope. The following are costs of rope.

MANILA TRANSMISSION ROPE

Diam., inches	Approximate wt. in lbs. per 100 ft.	Approximate breaking strength	Length in ft. required for splice	Smallest diam. of sheave
¾	20	4,500	8	28
⅞	26	6,125	8	32
1	34	8,000	10	36
1⅛	43	10,125	10	40
1¼	53	12,500	10	46
1⅜	65	15,125	12	50
1½	77	18,000	12	54
1⅝	90	21,125	12	60
1¾	104	24,500	12	64
2	136	32,000	14	72

Price 11 to 15½ cts. per pound.

Scales. The following are the costs of various types of scales. *Portable Platform Scales* adapted to the weighing of all kinds of general merchandise.

Capacity, lbs.	440 x ¼	800 x ½	1500 x ½	2500 x ½
Size of platform, ins.	16 x 22	17 x 26	21 x 28	26 x 34
Weight, approx., lbs.	125	200	300	400
Price without wheels	$13.00	$20.00	$30.00	$48
Price with wheels	15.00	22.00	33.00	51

Wheelbarrow scales, with runs on both sides for wheelbarrows and hand trucks.

Capacity, lbs.	1,000	1,500	2,000	2,500
Platform, ins.	42 x 30	42 x 30	44 x 35	45 x 36
Price without wheels	$42.00	$48.00	$49.00	$69.00
Price with quick weigher	66.00	....	....	....
Price with wheels	45.00	51.00	60.00	75
Price with quick weigher	69.00	....	....	....

A Steel Pitless Wagon Scale which can be easily moved at a cost of $20 to $30, complete with frame and scale costs as follows:

4 ton, weight 1,400 lbs.	Price	$100.00
5 ton, weight 1,500 lbs.	Price	110.00

Standard wagon and stock scales without timber or foundation cost as follows:

Capacity, tons	3	5	10	15	20
Size of platform, ft.	14 x 8	14 x 8	18 x 8	22 x 7	22 x 7
Price	$80.00	$100.00	$120.00	$210.00	$250

A Car Scale of 10 tons capacity, with a platform 4 ft. 6 ins. × 8 ft., costs, without platform, framing, or material for pit, $150. The frames take about 1,000 ft. b. m. of lumber and cost erected about $45. The foundation, including the boxing of the pit, will cost from $75 to $100.

A Steelyard or Weighmaster's Beam with a capacity of 2,000 lbs., beam 7 ft. 10 ins. long, weighing 127 lbs., costs $28.

A Track Scale for weighing of material in small cars costs as follows;

Capacity tons	2	3	5	6
Size of platform	5 ft. x 30 ins.	5 ft. x 30 ins.	5 ft. x 30 ins.	12 ft. x 30 ins.
Weight, lbs.	750	780	900	1,500
Price	$72	$80	$88	$130

Wooden parts for 2 and 3 ton scales $28 extra. For double beam add $5.

Cost of Track Scales. On the New York Central a 100-ton track scale, 42 ft. long, cost as follows, in 1902:

Scales and materials	$1,760
Labor	640
Total	$2,400
8.7 tons rails (relayers), at $20	174
15 ties at $0.60	9
Miscellaneous material	150
Labor laying track, etc.	70
Grand total	$2,803

No piles were used in foundation.

The cost of 50-ton track scales, 42 ft. long, on the Northern Pacific, in 1899, averaged as follows:

Scales, delivered	$ 580
Other materials	170
Labor ($175 to $300)	250
Total	$1,000

The cost of 80-ton track scales, 50 ft. long, in 1905, was as follows:

Scales and materials	$1,250
Labor ($500 to $700)	650
Total	$1,900

Steel. The following costs of steel are subject to considerable variation with the market.

Structural Shapes. The following prices were abstracted from Engineering and Contracting:

Structural shapes f.o.b. Pittsburgh:	1912 Cts. per lb. net	1917 Cts. per lb. net
I-beams and channels, 3 to 15 ins.	1.50	4.50
I-beams over 15 ins.	1.65	4.60
Angles, 3 to 6 ins.	1.60	4.50
Angles over 6 ins.	1.65	4.60
Tees, 3 ins. and up	1.65	4.50
Checkered and corrugated plates	2.80	9.00

Prices at Chicago for shipment from stock are as follows:

Angles, 3 to 6 ins.	2.0	5.0
Angles over 6 ins.	2.1	5.1

Beams and channels	2.0	5.0
Beams over 15 ins.	2.1	5.1

The New York quotations for structural shapes are as follows:

Beams and channels, 3 to 15 ins.	1.66@1.71	5.25
Angles, 3 x 3 up to 6 x 6	1.66@1.71	5.25
Tees	1.81@ ...	5.25
Steel bars, full extras	1.71@1.76	5.1 to 5.6

Plates. The corresponding prices for plates f.o.b. Pittsburgh on the basis of net cash in 30 days are as follows:

Tank plates, ¾-in. thick, 6¼ ins. up to 100 ins. wide, 1.55 cts. to 1.60 cts. base.

	1912	1917
Gages under ¼ in. to and including $\frac{3}{16}$ in.	$0.10	9.0 and over
Gages under $\frac{3}{16}$ in. to and including No. 8	.15	" " "
Gages under No. 8 to and including No. 9	.25	" " "
Gages under No. 9 to and including No. 10	.30	" " "
Gages under No. 10 to and including No. 18	.40	" " "
Sketches, 3 ft. and over in length	.10	" " "
Complete circles, 3 ft. diameter and over	.20	" " "
Boiler and flange steel	.10	" " "
A. B. M. A. and ordinary fire box steel	.20	" " "
Still bottom steel	.30	" " "
Marine steel	.40	" " "
Locomotive fire box steel	.50	" " "
Plates in widths over 100 ins. to 110 ins.	.05	" " "
Plates in widths over 110 ins. to 115 ins.	.10	" " "
Plates in width over 115 ins. to 120 ins.	.15	" " "
Plates in widths over 120 ins. to 125 ins.	.25	" " "
Plates in widths over 125 ins. to 130 ins.	.50	" " "
In widths over 130 ins.	1.00	" " "

Prices at Chicago for shipment from stock are as follows:

	1912	1917
¼-in. and heavier, up to 72 ins.	$2.00	9.0 and over
Over 72 ins.	2.10	" " "
$\frac{3}{16}$-in. thick	2.10	" " "
No. 8	2.15	" " "

The following were the New York quotations on plates, the prices being based on carload lots, with 5 cts. extra for less than carload lots. Terms, net cash in 30 days:

	1912	1917
Tank plates ¾-in. thick, 6½ to 100 ins. wide	1.71@1.76	9.0 and over
Flange and boiler steel	1.81@1.86	" " "
Marine	2.11@2.16	" " "
Locomotive and fire box	2.21@2.26	" " "
Still bottom	2.01@2.06	" " "

Plates more than 100 ins. in width, 5 cts. extra per 100 lbs.; plates $\frac{3}{16}$ in. in thickness, 10 cts. extra; gage Nos. 7 and 8, 15 cts. extra; No. 9, 25 cts. extra.

Sheets. The corresponding minimum prices for mill shipments from Pittsburgh on sheets in carload and larger lots are as follows:

	1912
Galvanized roofing sheets No. 28, 2½-ins. corrugations, per square	$3.00
Painted roofing sheets, No. 28, per square	1.70

	1912	1917
Galvanized sheets	$2.50 to 3.85	$9.0 to 10.25
Black annealed sheets	1.70 to 1.90	9.0 to 10.25
Blue annealed sheets	2.20 to 2.55	7.85 to 8.35

Freight Rates (1917). On finished steel products in the Pittsburgh district, including plates, structural shapes, merchant steel, bars, pipe fittings, plain and galvanized wire nails, rivets, spikes, bolts, flat sheets (except planished), chains, etc., the following freight rates are effective in cents per 100 lbs.:

Baltimore	15.4	Minneapolis	32.9
Boston	18.9	New Orleans	30.7
Buffalo	11.6	New York	16.9
Chicago	18.9	Pacific Coast (all rail)	75.0
Cincinnati	15.8	Philadelphia	15.9
Cleveland	10.5	St. Louis	23.6
Denver	68.6	St. Paul	32.9
Kansas City	43.6		

Cost of Drafting Equipment. The following are costs of typical drafting equipment:

1 beam compass	2	oz.	each	$6.00 to $12.20
1 dotting pen	1	oz.	each	0.80 to 6.80
1 railroad pen	1	oz.	each	2.00 to 3.00
1 set drawing instruments	16	oz.	each	6.16 up
2 German silver protractors 4 in.	2	oz.	each	1.35
6 in.				3.15
2 engineers' triangular scales, 12 in.	1	oz.	each	1.20 each
2 architects' triangular scales, 12 in.	1	oz.	each	2.00 "
2 45 deg. triangles 10 in.	1	oz.	each	.36 "
6 in.				.76 "
2 30–60 6 in.	1	oz.	each	.24 "
10 in.				.52 "
1 set railroad curves	5	lb.	each	6.91
				11.9
1 set French curves	5	lb.	each	9.26
2 T squares 36 in.	8	oz.	each	.44
36 in.	5	lb.	each	.84
30 in. x 42 in.				13.05
1 blue print frame				
1 plan case	50	lb.	each	18.00
Thumb tacks				1.28
Water colors, 20 colors at $0.18 a pan				3.60
Higgins Inks, 16 colors at $0.25 a bottle				4.00
1 current meter	5	lb.	each	45.50
2 leveling rods, Philadelphia	5	lb.	each	13.50 each
2 Florida rods, 12-ft.	3	lb.	each	9.00 "
3 range poles, 10-ft.	3	lb.	each	2.25 "
3 plumb bobs	¾	lb.	each	1.80 "
Stake tacks	5	lb.	each	1.35
2 tape mending tools	1	lb.	each	3.60
2 steel tapes, 100-ft.	2	lb.	each	10.32
2 steel tapes, 50-ft.	1	lb.	each	6.00
1 cloth tape, 100-ft.	1	lb.	each	3.28
1 planimeter	1	lb.	each	25.20
1 pantograph	1	lb.	each	4.50

Cost of Transits. A low priced and yet reliable transit, known as a builder's transit, weighs 6 lbs. and costs $85; with compass, 3-in. needle, $100. The tripod weighs 6 lbs.

A light mountain transit with a 7½-in. telescope, a 4-in. needle, complete, costs $200. Weight, instrument 5½ lbs., extension tripod, 7 lbs.

Mountain and mining transits with 9½-in. telescope and 4-in. needle, cost complete $235. Weight, instrument 10 lbs., tripod 9 lbs.

Surveyors' transits with a 5-in. needle weigh 16½ lbs. and cost $160.

Engineers' transits complete cost from $175 to $250 and weigh from 9 to 15 lbs.

Valves. The following are costs of typical valves.

Size, ins.	Net price	Size, ins.	Net price
10	$45	22	$210
12	64	24	240
14	88	25	260
15	100	26	280
16	110	28	320
18	140	30	360
20	170		

Straight-way wedge gate valves with bolted cap and flanged ends, for working steam pressures up to 125 lbs.

STANDARD BRASS

Size, ins.	Net price	Size, ins.	Net price
¼	$0.55	1	$1.25
⅜	.58	1¼	1.70
½	.68	1½	2.25
¾	.95	2	3.50

Straight-way wedge gate valves with screwed cap and ends, for working steam pressures up to 125 lbs.

STANDARD IRON BODY AND BRASS TRIMMINGS

Size, ins.	Net price	Size, ins.	Net price
2	$4.50	5	$14.50
2½	5.75	6	18.50
3	7.40	7	22.50
3½	9.00	8	27.00
4	11.00	9	31.00
4½	12.00	10	35.00

Straight-way wedge gate valves with bolted cap and screwed ends, for working steam pressures up to 125 lbs.

STANDARD BRASS GLOBE VALVES

Size, ins.	Net price	Size, ins.	Net price
⅛	$0.40	1½	$2.10
¼	.42	2	3.40
⅜	.48	2½	5.00
½	.55	3	7.25
¾	.80	3½	10.00
1	1.10	4	13.50
1¼	1.60		

These valves have screwed cap and ends, for working steam pressures up to 125 lbs.

STANDARD IRON BODY GLOBE VALVES WITH BRASS TRIMMINGS

Size, ins.	Net price	Size, ins.	Net price
4	$8.00	7	$23.00
4½	10.00	8	30.00
5	12.00	9	38.00
6	17.00	10	45.00

Bolted cap and screwed ends, for working steam pressures up to 125 lbs.

For flanged end connections there is about 10% increase on the above prices.

EXTRA HEAVY IRON BODY

Size, ins.	Net price	Size, ins.	Net price
4	$22	9	$60
4½	25	10	72
5	28	12	105
6	35	14	150
7	43	15	200
8	54	16	250

Straight-way gate valves with bolted cap and flanged ends, for working steam pressures up to 250 lbs.

EXTRA HEAVY BRASS GLOBE VALVES

Size, ins.	Net price	Size, ins.	Net price
¼	$0.80	1¼	$3.30
⅜	.92	1½	4.70
½	1.10	2	8.00
¾	1.60	2½	11.00
1	2.30	3	16.00

These valves have screwed cap and ends, for working steam pressures up to 250 lbs.

EXTRA HEAVY BRASS GLOBE VALVES

Size, ins.	Net price	Size, ins.	Net price
¼	$0.80	1¼	$3.30
⅜	.92	1½	4.70
½	1.10	2	8.00
¾	1.60	2½	11.00
1	2.30	3	16.00

These valves have screwed cap and ends, for working steam pressures up to 250 lbs.

EXTRA HEAVY BRASS VALVES

Size, ins.	Net price	Size, ins.	Net price
⅜	$2.20	1¼	$5.00
½	2.30	1½	6.60
¾	2.85	2	10.50
1	3.80	2½	15.00

These valves are straight-way wedge gate valves with screwed cap and ends for working steam pressures up to 250 lbs.

EXTRA HEAVY IRON BODY AND BRASS TRIMMINGS

Size, ins.	Net price	Size, ins.	Net price
2	$10	5	$26
2½	13	6	32
3	15	7	40
3½	18	8	50
4	20	9	60
4½	23	10	71

Straight-way wedge gate valves with bolted cap and screwed ends, for working steam pressures up to 250 lbs.

Etching Tools for Identification Purposes. J. J. O'Brien (Power and the Engineer, Jan., 1909) states that the best way to mark names or initials on metal tools is to etch them. The mark is ineffaceable and easily done, with a little experience.

The first step in the process is to spread a thin layer of soap over the surface intended to be used. Next, with a sharp stick, or scratch awl, cut the name in the layer of soap, exposing the metal. Then drop into the letters enough of the following solution to commence an oxidizing action on the metal exposed: One ounce salt, 2 ounces copper sulphate (bluestone), and 1 quart of vinegar. A few drops will suffice, and a few trials will teach how long to let the solution work before wiping it off with a cloth.

Painting Materials Required and Surface Covered per Gallon. G. B. Barham in the Surveyor, Apr. 25, 1913, gives in Table VII the amount of materials of ordinary kind required to make one gallon of paint mixed in linseed oil and the area covered therewith.

TABLE VII. PAINTING MATERIALS REQUIRED AND SURFACE COVERED

Paint	Pounds of pigment	Weight and volume of paint	Sq. ft. covered first coat	Sq. ft. covered second coat
Red lead	22.4	30.4 = 1.4	630	375
White lead	25.0	33.0 = 1.7	500	300
Iron oxide	24.75	32.75 = 2.6	600	350
Graphite	12.5	20.50 = 2.0	630	375
Asphalt	17.5	30.0 = 4.0	500	300

Light structural steel work averages about 250 sq. ft. per ton of metal; heavy work about 150 sq. ft. per ton; corrugated steel (No. 20) about 2,400 sq. ft. of surface per ton. Roughly, ½ gal. of paint per ton of structural steel is required for a first coat, and ⅜ gal. for second coat, under average conditions. Detail costs of labor and materials for painting are given in Gillette's Handbook of Cost Data.

Cost per Sq. Yd. of Cleaning and Painting Draft Tubes. Barry Dibble (Engineering and Contracting, Sept. 8, 1915) gives the

following costs for the Minidoka plant, U. S. Reclamation Service.

In scraping we found an excellent adherence between the metal and the tar paint, which had been on 1½ years at that time. Where it was scraped down to the metal it left a bright surface. On one patch, of about 1 sq. yd., apparently the iron had not been well cleaned before applying the paint, as it was in a place difficult to reach, and here scale had formed on the iron, but this was the only place the iron had not been protected from the water. There was a marked difference in the ease with which this tar was cleaned off preparatory to repainting as compared with the work involved on surfaces which had been covered with red lead paint, and which had become pitted.

There was quite a variation in the consistency of the water-gas tar purchased at different times. As ordinarily obtained, it was necessary, in the cool weather during which we painted, to mix a little gasoline with it. Usually the mixture was about 1 quart of

TABLE VII. COST OF CLEANING AND PAINTING FIVE DRAFT TUBES

	Total
Total surface, sq. yds.	850
Area cleaned and painted, sq. yds.	750
Cost of scaffolding:	
Labor	$52.32
Material	22.74
Cost of cleaning:	
Sharpening scrapers	52.76
Labor	321.78
Cost of painting, labor:	
First coat (water-gas tar)	41.62
Second coat (coal-gas tar)	59.96
Third coat (coal-gas tar)	8.50
Total labor, painting only	110.08
Material (all coats)	10.39
Total cost	$570.07
Cost per sq. yd. cleaned and painted:	
Scaffolding, labor and material	$0.100
Cleaning, sharpening scrapers, and labor	.499
Painting—	
Labor	.147
Material	.014
Total per sq. yd.	$0.760

gasoline to from 3 to 5 gals. of tar. This tar was then spread on carefully with a brush in the same manner as ordinary oil paint, working it carefuly into all pits and around rivets. One gallon of tar covered about 30 sq. yds. with one coat. The cost

was about 15 cts. per gallon, about one-half of which was freight charge from Chicago to Minidoka.

The tar is rather slow in setting even if the weather is warm. It hardens when the thermometer drops, but when the weather warms up will become sticky even after a considerable period. As most of our work was done in cool weather, it was possible to apply the second coat within 10 to 14 days. In only one case were we able to get a third coat on prior to the time when the weather turned so bad that it was impossible to do outside work. It does not appear to affect the tar to put it into the water before it is thoroughly hardened.

Cost of Sand Blast Cleaning of Structural Steel. G. W. Lilly (Proceedings of American Society of Civil Engineers, February, 1903) states that in cleaning several steel viaducts in Columbus, Ohio, in 1902 two Newhouse sand-blast machines, mounted on light trucks, so that they could be moved about and placed where convenient for the work, were used. A wire-bound, 1½-in., rubber air-hose, 50 ft. in length, connected each machine with the 2-in. air pipe. Old rubber hose, which was much cheaper than new, was used for the sand hose, part of it being 2¼ and part 2½ ins. in diameter. The nozzles used were ½-in., extra heavy, gas pipe, of various lengths, from 12 to 24 ins. A length of at least 12 ins. seems to direct the blast with more effect than a shorter one. This was used instead of tool steel or other hard pipe because it was believed that it would last nearly as long and cost much less. The average length of time one nozzle lasted was about 5 hours, as shown by the length of pipe used and the total hours run. The nozzle was connected to the sand hose by a heavy, special cast reducer, about ¾ in. thick. This reducer was made thick, to sustain the wear caused by the deflection of the sand into the small nozzle pipe. The most severe wear of the nozzles is at a point 3 ins. from the connection with the reducer.

It will be noted that the sand, in passing from the large sand hose to the small nozzle, is deflected so as to produce a cross-fire, striking with greatest force against the sides of the small pipe near the reducer end. A like wear upon the rubber sand hose occurs near its connection with the pipe from the machine, which is a 1¼-in. pipe, and the spreading out of the sand to form the larger stream causes it to strike against the sides and then deflect to follow the direction of the hose. One foot in length, or sometimes a little more, cut from this end of the hose occasionally, fitted it for further use. The length of sand hose used varied from 25 to 65 ft., being regulated by the distance of the work from the place where the machine had to be placed. As the machines could not be placed upon scaffolding, in this work, at least 35 ft. of hose were required on nearly all the work, so as to reach from the ground to the floor system, from 16 to 20 ft. above the tracks, and in some places out over the tracks as far as 30 to 40 ft.

The nozzlemen should be men of some judgment and intelligence,

so that they will understand how to manage the nozzle to make the blast most effective. When ready for work the nozzleman wore a helmet of tin, with cloth curtains hanging to the shoulders to keep out the dust, as far as possible. Instead of using wire gauze in the helmet, two pieces of glass were used for the nozzleman to see through, because it excluded the dust more effectually. When frosted over by rebounding sand, the glasses were removed and new ones inserted. After a little experience, a good nozzleman will learn how to hold the nozzle in any given case, varying its distance from the working point according to the manner in which he finds it is operating. Heavy scale requires him to hold the nozzle close, and light cleaning can be done more rapidly by holding it farther away and permitting the blast to spread somewhat and thus cut a wider swath. On moderately hard places about 5 to 6 ins. is the proper distance. To make it clean most rapidly he must also direct the blast so as to cut a swath clean as he goes, passing first in one direction and then in the other, across the member being cleaned, so as to leave no spots to which he must go back and thus waste the force of the blast on clean metal around them. The nozzle should generally be directed so as to strike the surface at a slight inclination from the normal, say 20 to 30 degs. away from the nozzleman, thus blowing the dust and sand away. The cleaning should be carried forward from the nozzleman, so that the blast will always act upon the exposed edge of scales, rust, or old paint, and, by getting under any loose portions, throw them off without first having to break them up.

The compressed air was supplied from a compressor with an air cylinder of 14 ins. diameter and a stroke of 12 ins., compressing the air to a gauge pressure of 50 to 60 lbs. The number of strokes was regulated automatically so as to keep the pressure nearly constant. The air was led from the compressor to a large receiver, and then, by a line of 2-in. steel pipe, to a small receiver at the viaduct where the work was to be done. From this receiver (having a capacity of about 9½ cu. ft.) the air was conducted to the sand-blast machines. The pressure at the machines was usually from 30 to 40 lbs. The requisite length of 2-in. pipe varied from about 1,250 to 2,200 ft. The small receiver had a pet-cock in the bottom to let out accumulated water, and it removed much of the moisture from the air used.

The compressed air was paid for by the city, at the rate of 40 and 45 cts. per hour for one machine, and 60 cts. per hour for two machines in operation. For 18% of the time only one machine was in operation. This made the work cost more, because two machines could have been operated for about one and one-half times what one would cost. A foreman, 2 nozzlemen and 3 laborers could operate 2 machines and dry the sand for them. The foreman was paid 35 cts., nozzlemen 25 cts., and laborers 15 cts. during one-half of the time, and after that 17½ cts. per hr.

The sand used was from Lake Erie. An attempt was made to secure rather coarse, clean and sharp sand; but it was at times

impossible to do this without some delay, and some of the sand used was too fine and made much dust on account of the silt it contained. The sand was at first dried in two old locomotive ash pans, with old ties for fuel. This required almost constant attendance by one man, to stir it up and keep it from becoming so hot as to make the grains brittle and ineffective.

The dryer was made by fitting a sheet-steel hopper on an old cast-iron stove. The wet sand would not fall through the ¾-in. holes in the lower part of the hopper, but would as soon as dry. The sand was permitted to cool for a few hours before being used, as hot sand caused steam and was likely to choke the small opening in the bottom of the hopper, around the end of the siphon nozzle. The objection to this kind of a dryer is that the fire-pot, being surrounded by sand in contact with it, burns out in a short time. Two fire pots were required in six months' service.

All the viaducts named have buckle-plate floor systems, exposing a large amount of steel surface to the action of rust and corrosion. It may be well to state the conditions under which the work of cleaning had to be done, in order to give a better understanding of the items making up the cost. The data here given may then be better analyzed and applied to any other proposed sand-blast cleaning. The first four viaducts named were erected during 1893 and 1894 and all were repainted during August and September, 1896, and none of them had been repainted since that time. No. 5 was erected in the latter part of 1893, repainted in August, 1896, and again in October, 1899. The cleaning done before repainting, in each of these cases, was only hand-cleaning. All appearances indicate that the steel of No. 4 must have been in better condition than that of any of the other viaducts, and a better quality of paint must have been applied at the time of its erection. This is judged largely from the condition of the portions of the viaducts above the level of the street pavement and protected by it from the direct action of the blast and gases from the locomotives. The portions below the pavement, on all the others, are subjected to greater wear by the locomotive blast on account of their small clearance above the stacks, their clearness above the level of the railroad tracks being only 16.33 to 16.75 ft., while this viaduct has a clearance of 20.33 ft. In cleaning them, therefore, it was impossible to swing any staging below the clearance elevation, in the case of four of them. No. 5 and No. 2 do not afford sufficient space above the lower surface of the plate girders in which a man can work, and it was necessary to work from movable trestles, about 12 ft. high, made as light as possible, so that they could be moved off the tracks whenever a train or an engine was about to pass, and be replaced and the work continued when the track was clear.

Under the first three viaducts mentioned there are two main tracks and one side track, with a spur track from the middle of the first, making four tracks under the east half of it.

Movable trestles were also used, part of the time, in cleaning the cover plates on the bottom of the girders and the portion of

the work along the abutments of No. 3; but a large portion of the cleaning was done from staging resting upon the lower cover plates and angles of the plate girders.

TABLE IX. COST OF SAND-BLAST CLEANING OF VIADUCTS AT COLUMBUS, OHIO

No.	Number of square feet cleaned	Cost per square foot	Square feet cleaned with 1 cu. ft. of sand	Square feet cleaned per hour by one sand-blast	Average pressure at sand-blast, in pounds per square inch
1	24,900	$0.0283	17.1	64	35
2	8,000	0.0362	10.4	49	37
3	17,000	0.0263	18.2	66	35
4	63,000	0.0174	25.2	89	30
5	22,600	0.0688	6.1	23	33
Totals and averages	135,500	$0.0302	14.8	54	33
Excluding No. 5	112,900	0.0225	20.0	74	33

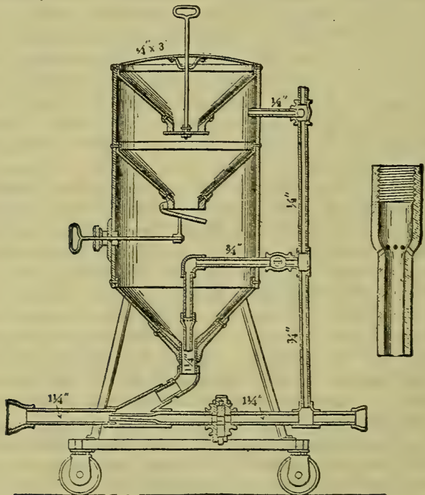


Fig. 2. Newhouse sand blast machine.

Electric Arc Welding Apparatus. Standard 300 amp., single unit belted type, with two metallic circuits or one graphite and one metallic, cost $1,325.

Standard 300 amp., motor generator set, consisting of a welding generator, and either d.c. or a.c. motor, with two metallic circuits or one graphite and one metallic circuit, cost $1,650.

Cost of Electric Welding in a Pittsburgh Shop. An electric welding outfit used by the Pittsburgh Railway Co. is described in Electric Railway Journal, Nov. 18, 1911, as follows:

Current for welding is furnished by an old GE booster set consisting of a 30-h.p. shunt-wound motor and a 60-volt, 300-amp. generator. Nevertheless, the actual output of the generator can be varied from 300 amps. to 700 amps. at 80 volts to 110 volts, according to the conditions desired. There is enough reactance in the generator to take care of sudden surges when the welding arc is broken. The shunt field of the booster is directly excited from the trolley circuit through a resistance connected in series with it across the line instead of being shunted around the series winding of the generator. The switch controlling this separately excited shunt-field circuit is locked to prevent anyone from breaking this circuit when the set is running free. The grid resistances, which are inserted in the series field in series with the armature, can be varied from 0.02 ohm. to 0.045 ohm., depending upon the amperage desired.

The welding flux consists of 17 parts borax, 1½ parts brown oxide of iron and 1½ parts red oxide of iron. The electrodes are usually of carbon, but cold rolled steel is used for such work as welding sheet steel on a gear case, the melting of the electrode itself furnishing the required new metal.

The economies of this method of welding may be appreciated from the following typical cases, which give the price of certain parts new, their value as scrap and the cost of rehabilitating them for service. In each case 15% is added to the shop cost to allow for overhead shop charges. Welding labor is figured at 30 cts. an hr. and electrical energy at ½ct. per kw.-hr.

TABLE X. COST OF ELECTRIC WELDING

Article	New	Labor welding	Carbons and flux	Power	Overhead charges
Bemis side frame	$26.25	$0.88	$0.37	$1.92	$0.48
Lord Baltimore side frame..	28.00	0.33	0.05	0.72	0.17
McGuire Columbian side frame	35.00	0.33	0.05	0.72	0.17
Westinghouse No. 56 motor frame	....	0.99	0.17	2.16	0.50
Westinghouse No. 62 motor gear case lugs..........	....	0.22	0.21	0.48	0.14

Cost of Electric Welding in a Railroad Shop. G. W. Cravens (Railway Electrical Engineer, June, 1913) states that electric welding outfits supplied by the best makers consist of the motor-generator, controlling panel, electrode holders, head and hand shields for the operators and a supply of electrodes. The head shields have a window of red and blue glasses to protect the eyes of the operator from the blinding glare of the arc. The combination system outfit includes a patented combination electrode holder

for taking both a graphite and a metallic electrode, so it is possible to change from one to the other method by simply throwing a switch on the holder.

With the Bernardos system, using a carbon or graphite electrode, the current required will range from 110 to 800 amps. per circuit, and with the Slavinoff system, using metallic electrodes, the current will vary from 25 to 200 amps., depending upon the nature of the work, the size of the piece being manipulated and the material. The usual operations with the metallic electrode, however, require but from 50 to 100 amps., and with the graphite electrode from 300 to 500 amps., the latter being used for cutting purposes frequently.

The following figures show the cost of several actual jobs done with the electric welding arc outfits, the labor being paid at 30 cts. per hr. and the current at 2 cts. per kw.-hr. All of these were done by men of ordinary ability after being instructed by the manufacturer's demonstrators:

Steel castings, shrinkage crack 6 ins. long by 1 in. deep	8 min.	$0.04
Steel casting, riser 4 ins. by 4 ins. cut off	4 min.	.05
Forged steel locomotive frame, broken in 2 places	20 hrs.	18.28
Crack in back sheet of locomotive boiler, 12 in. long	9 hrs.	5.47
Building up worn driving wheel instead of turning down	2 hrs.	.72
Welding 67 cracks in old fire box (saving over $1,000)	2 weeks	52.60
Cast steel tender frame, broken in 3 places	27 hrs.	19.00
Steel shaft, 2 in. diameter, welded ready for returning	1 hr.	.60
Broken railway type motor case, cast steel	3 hrs.	1.95
Enlarged holes in brake levers, steel bars	4 min.	.05
Building up 2-in. armature shafts, worn in journals	3 hrs.	1.80
Air brake piston rods, broken	30 min.	.35
Leaking axle boxes, cracks, welded in place	15 min.	.15

The foregoing covers but a few of the many kinds of jobs which continually arise in locomotive and car shops, but will give a fair general idea of what can be done. The following list shows what was done in one of the largest street railway shops in the far West with a graphite arc outfit:

	Cost	New
Armature shaft repaired in place	$1.70	$ 4.72
Armature shaft repaired in place, large	1.97	15.13
Railway motor axle cap, large	.22	3.51
Railway motor armature bearing cap	.27	6.07
Railway motor gear case, top half	.48	7.30
Truck side frame, Brill 27-G	.72	44.40
Brake-heads, building up worn sockets	.06	1.15
Grip crotches	.72	10.00
Truck side frame, Peckham 14-B	.90	46.98
Motor frame, GE-90 railway type	2.88	16.80

The following figures have been compiled in various steam railroad shops and show the comparative savings which can be effected by using the electric arc system for making repairs. The

comparisons here are made between the electric system and the old methods, whatever they may be:

	Cost	Old
Engine main frames, both broken	$11.80	$ 56.20
Driving wheel built up 3/16 ins. on tread	.72	8.00
General repairs on fire box side sheets	66.51	342.62
Filling in worn knuckle joint bush hole	.75	7.50
Locomotive cylinder casting, 7 cracks	22.35	367.15
Broken mud ring on locomotive boiler	32.07	118.06

Cost of Electric Welded Rail Joints in Camden, N. J. In welding rails in Camden, N. J., in 1906 it is stated in Street Railway Journal, Jan. 6, 1906, that all of the joints welded were in a more or less battered condition, so that the joints had to be raised before being welded. This was done by raising the receiving rail so that the lowest point in this rail was level with the head of the abutting rail, after which the elevations were ground off with a corundum wheel. It has been found that the electric weld holds the rail absolutely firm and that the rolling of wheels across the joint since the work was finished has tended to make the joint smoother than it was immediately after the welding. It is true that by grinding off a portion of the head of the rail some of its wearing qualities are sacrificed. The experience at Camden, however, has been that this is necessary and that the battered end of the rail must be ground level before a good joint can be obtained.

The following table summarizes the cost of electrically welding joints, including contract price of $5.25 per joint. As will be seen

TABLE XI. COST OF ELECTRICALLY WELDING 3087 JOINTS IN CAMDEN, N. J.

Cost of labor	$7,031.24
Cost of material	581.09
	$7,612.33
Credit from sale of old fish-plates and bonds	2,816.59
	$4.795.74
Cost of welding 3087 joints, at $5.25 each	$16,206.75
Cost of replacing asphalt, 899.6 yds., at $2.53; 117 yds., at $2.51	2,569.65
Total cost of operation	$23,572.14
First cost per joint, labor	2.277
First cost per joint, material	.188
First cost per joint, labor and material	2.465
Cost per joint, labor and material, after credit is deducted	1.553
Final cost per joint, all labor, material, welding and asphalt charges	7.635
Cost per mile, under similar conditions, 30-ft. lengths	2,687.52
Cost per mile, under similar conditions, 60-ft. lengths	1,343.76

from these tables, the cost per joint varies from $6.632 to $10.438, with an average of $7.635. This price, however, should be considered in connection with the maintenance charge of the joint with which this price is compared. It is estimated that the life of the welded rail on the Haddonfield Pike will be 8 years, whereas

during the last 2 years with angle plate joints this track has cost the company about $1 per joint each year for tightening bolts and shimming. This maintenance work has only temporarily relieved the situation, for each year the joint has been worse, and it was estimated that at the end of 4 years the rail would have been so bad at the joints that the track would have to be relaid. In other words, it is expected that in this particular case, by electrical welding, the life of the rail will be practically doubled at a less cost than would have been required simply for maintaining angle plate joints during the life of the rail.

Costs of Electric-Arc Welding for typical jobs in railway locomotive shops were given by G. W. Cravens, Manager of Welding Department, C & C Electric Manufacturing Co., Garwood, N. J., in a paper before the Southern & Southwestern Railway Club, at Atlanta, Ga., in 1915. There was quoted $32 for repairing a broken locomotive-boiler mud ring (cutting out corner of plate, welding ring in place, welding back pieces of plate and driving a few new rivets) compared with $118 for the old method (stripping, removing ring for welding in blacksmith shop, resetting, replacing locomotive parts, etc.). Applying new fireboxes cost $56 (welding three short sheets) compared with $777 by the old scheme (stripping, transferring boiler, removing old firebox and building up new one, adding stay and crown bolts and mud ring, overhauling and refitting, etc.). With an outfit costing $2,000, the following was done with current at 2 cts. per kw.-hr. and labor at 30 cts. per hr.:

	Welding	Old methods
Mending both main frames	$11.80	$56.20
Driving wheel built up 3-16 in. on tread....	2.72	8.00
General repairs on firebox side sheets....	66.51	342.62
Filling in worn knuckle-joint hole..........	.75	7.50
Repairing seven cracks in cylinder casting.	22.35	367.15

The following costs had no old figures for comparison:

	Cost
Steel casting, shrinkage crack 1 x 6 in. in 8 min.	$0.04
Forged-steel locomotive side-frame, two breaks in 20 hrs.	18.28
Welding 67 places in old firebox in 12 days................	52.60
Cast-steel tender frame, broken in three places, in 27 hr....	19.00
Cast-steel motor case, welded in 3 hrs.	1.95
Welding broken air-brake piston rod, in 30 min.	.35
Leaky axle box, crack welded without removing box, in 15 min.	.15

Cost of Electric Welding in Railroad Shop Repair Work. The accompanying data on repair costs due to electric arc welding have been compiled by the Westinghouse Electric & Manufacturing Company from the shop records of railroad companies. One railroad company which has kept continuous records of the savings made by arc welding reported that the total cost of welding by this process during one week was $106.62, while the total cost of the same work if done by other means would have been $1,779.04, representing a net saving of $1,672.42 in favor of arc welding. In addition a great saving in time was made. In an-

other case, where an entire firebox had to be taken out, the work, including 35 ft. 7 ins. of linear cutting, was done in 38 mins. with approximately 500 amps.

TABLE XII. COST OF ELECTRIC WELDING IN REPAIR WORK

	Energy	Labor	Material	Total
Cracked door sheet on fire box	$0.09	$0.30	$0.12	$0.51
Cracked side sheets and door sheets in fire boxes	...	...	...	4.23
Cracked crown sheet	...	1 hr.	...	0.36
Broken frame	...	7 hr.	...	3.29
Worn wrist pin	0.10	0.75	0.15	1.00
Cracked steel bolsters	0.54	5.42	0.75	6.71
Cracked guide yoke	0.07	0.45	0.10	0.62
Cracked mud ring	0.27	1.95	0.37	2.59
5 draw-head stops	1.30	1.15	0.18	2.63
Broken cylinder	0.80	0.65	0.11	1.56

Cost of Electric Welding in Railroad Shops. Some interesting figures on the cost of electric welding and the time required for various jobs are shown in the accompanying table of data based on the experience of several leading railroads as reported to the shop-practice committee of the Association of Railway Electrical Engineers in 1913.

Steel casting, crack 6 ft. long by 1 in. deep, 8 min.	$0.04
Steel casting, riser 4 in. by 4-in. cut-off, 4 min.	0.05
Forged-steel locomotive frame, two breaks, 20 hrs.	18.28
Crack 12 in. long in boiler back-sheet, 9 hrs.	5.47
Cast-steel tender frame, three breaks, 27 hrs.	19.00
Broken railway-type motor case, cast steel, 3 hrs.	1.95
Enlarged holes in brake levers, steel bars, 4 min.	0.05
Air-brake piston rods, broken, 30 min.	0.35
Cracked axle boxes, welded in place, 15 min.	0.15

Speed of Electric Welding. O. A. Kenyon (Boiler Maker, Apr. 1914) gives the curve, Fig. 3, showing the time in minutes required to weld steel plates of different thicknesses and by different methods of cutting the joints. In these curves no allowance has been made for time required to change welding pencils or prepare the work. They cover simply the actual time of welding. Ten seconds is sufficient time to allow for changing a welding pencil by properly trained men.

Thermit Process Welding. Thermit is a mixture of finely divided aluminum and iron oxide. When ignited in one spot, the combustion so started continues throughout the entire mass without supply of heat or power from outside and produces superheated liquid steel and superheated liquid slag (aluminum oxide). The thermit reaction produces an exceedingly high temperature, the liquid mass attaining 5,400 degs. in less than 30 secs. The liquid steel produced by the reaction represents one-half of the original thermit by weight and one-third by volume.

Welding by the thermit process is accomplished by pouring superheated thermit steel around the parts to be united. Thermit

steel, being approximately twice as hot as ordinary molten steel, dissolves the metal with which it comes in contact and amalgamates with it to form a single homogeneous mass when cooled. The essential steps are to clean the sections and remove enough metal to allow for a free flow of thermit steel. surround them with a mold, preheat by means of a gasoline torch and then pour the steel.

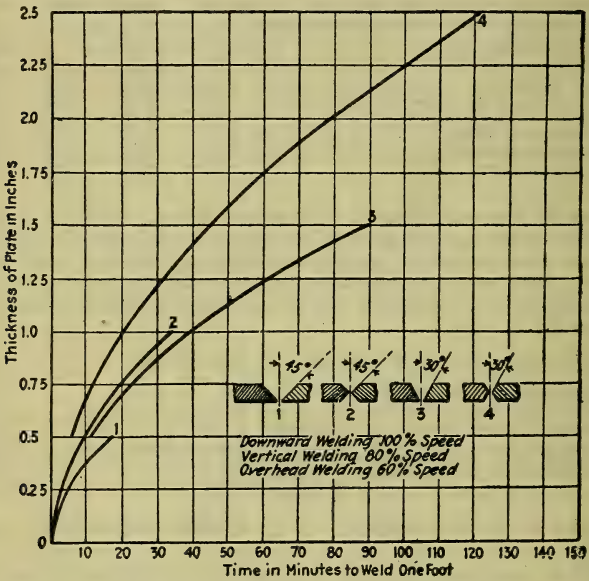


Fig. 3. Speed of electric welding.

The following detailed outfit is suitable for repair work on a small railroad or the equipment of a contractor, where the sections of wrought iron or steel do not exceed 4 × 6 ins. in size.:

Item	Price
1 automatic crucible No. 6	$ 16.50
1 double burner thermit preheating torch complete	75.00
1 tapping spade	.50
300-lb. thermit mixed with 1% manganese and 1% nickel thermit	78.90
10 lbs. yellow wax at $0.35	3.50
1 bbl. special moulding material for facing	4.00
45 lbs. mild steel punchings at $0.02½	1.13
1 lb. ignition powder	.90
Total cost, f. o. b. Jersey City	$180.43

The preheater is a permanent appliance and will last indefinitely, while the crucible will last from 16 to 20 reactions, after which it may be relined with magnesia tar in the field or at the factory for $11.50. Each crucible requires 135 lbs. tar at 3 cts. per lb., and one magnesia stone. No construction equipment is required except that it will be necessary to make a mold box out of sheet iron. Five extra packages of plugging material and four extra thimbles are supplied with each crucible. Extra packages and thimbles cost 10 cts. each.

The prices of other sizes of appliances are as follows:

Item	Weight (lbs.)	Price
Preheater torch, single burner	175	$50.00
Preheater torch, double burner	200	75.00
Automatic crucible, No. 1, for 4 lbs. thermit	40	3.50
Automatic crucible, No. 2, for 7 lbs. thermit	60	5.50
Automatic crucible, No. 3, for 16 lbs. thermit	110	6.50
Automatic crucible, No. 4, for 24 lbs. thermit	125	8.00
Automatic crucible, No. 5, for 45 lbs. thermit	150	11.00
Automatic crucible, No. 6, for 75 lbs. thermit	225	16.50
Automatic crucible, No. 7, for 135 lbs. thermit	385	30.00
Automatic crucible, No. 8, for 200 lbs. thermit	480	35.00
Automatic crucible, No. 9, for 260 lbs. thermit	580	43.50
Automatic crucible, No. 10, for 400 lbs. thermit	720	55.00
* Tripods, No. 1	11	2.10
* Tripods, Nos. 2–3	19	2.50
* Tripods, Nos. 4–5	24	3.00
* Tripods, Nos. 6–7	65	5.50
Flat bottom crucible, No. 2, for 4 lbs. thermit	18	1.75
Flat bottom crucible, No. 3, for 8 lbs. thermit	27	3.00
Flat bottom crucibles, No. 4, for 16 lbs. thermit	65	4.75
Flat bottom crucibles, No. 5, for 40 lbs. thermit	95	7.00
Tongs for flat bottom crucible, No. 2	6½	2.00
Tongs for flat bottom crucible, No. 3	17½	2.50
Tongs for flat bottom crucible, No. 4	25	3.25
Tongs for flat bottom crucible, No. 5	30½	4.50
Cost of relining flat bottom crucible, No. 2	...	.75
Cost of relining flat bottom crucible, No. 3	...	1.25
Cost of relining flat bottom crucible, No. 4	...	2.50
Cost of relining flat bottom crucible, No. 5	...	4.00
Thermit (sold only in 50 and 100-lb. drums).		
50-lb. drum	55½	12.50
100-lb. drum	110	25.00
Thermit with 1% manganese and 1% nickel thermit.		
50-lb. drum	56½	13.15
100-lb. drum	112	26.30
Ignition powder, ½-lb. cans	...	.45
Ignition powder, 2-lb. cans	...	1.80
Metallic manganese, per lb.	...	.75
Nickel thermit, per lb.	...	.55
Yellow wax, per lb.	...	.35
Special moulding material, per bbl.	375	4.00

* (For welding connecting rods and driving wheel spokes, etc.)

The proper quantity of thermit required for the weld may be calculated by multiplying by 32 the weight of the wax necessary to fill all parts of the fracture and reinforcement, or else by calculating the number of cu. in. in the fracture and reinforcement, multiplying by 2. To produce 4½ ozs. or one cu. in of steel requires 9 ozs. of thermit. If more than 10 lbs. of thermit

are to be used it is necessary to mix steel punchings, not exceeding ½ in. in diameter, or particles of steel into the powder. For 10 lbs. or more of thermit 10% of punchings should be added; for 50 lbs. or more, 15% of small mild steel rivets should be mixed in 1% each of manganese and nickel thermit should be added also.

Method and Cost of Welding Rails by the Thermit Process. The following account of the methods and cost of welding a large number of rail joints by the thermit process has been obtained from Mr. M. J. French, engineer maintenance of way of the Utica & Mohawk Valley Electric Railway.

Thermit Process. The process of welding consists in pouring molten mild steel from a melting crucible into sand and flour molds placed around the rails at the joint. It is in detail as follows:

The rails having first been lined and surfaced, the joint is thoroughly cleaned with a sand blast or wire brush. Then the rails are heated by a gasoline or oil blow-torch to expel all moisture, and by heating the rails to a dull red better results are secured as the temperature of the molten steel is not reduced as much when coming into contact with the rails. After the joint is cleaned and heated a pair of molds made of an equal mixture of common clay and sand, or, preferably, of sand and 10% of cheap rye flour, is clamped firmly to the rails. The molds are held by a wrought iron framework provided with handles to facilitate carrying. The molds being in place, the rail head is painted with a watery solution of red clay which the heated metal immediately dries up to a thin coating, the purpose of which is to prevent the molten slag or steel from uniting with or burning the rail head. After thoroughly luting all joints of the molds with clay of the consistency of putty, earth is packed around the outside of the molds. The molds and the rails are then given a final warming with the blow-torch, the flame being directed inside the molds to expel any remaining moisture. The crucible on its tripod is then set over the mold with its pouring hole directly over and about 2 ins. above the gate in the mold. After placing the tapping pin, iron disc, asbestos disc and refractory sand in the bottom of the crucible to act as a plug for the opening the thermit compound is poured in and in the center of the top is placed about one-third teaspoonful of ignition powder. A storm match starts the chemical process.

The thermit compound is composed of aluminum and iron oxide, both in granular or flake form; the ignition powder is composed of aluminum and barium peroxide in much finer form. When the match is applied the barium peroxide ignites and releases its oxygen to the aluminum very quickly. The heat produced is so intense that it causes the iron oxide to release its oxygen, which in turn is seized by the aluminum and almost instantly the entire contents of the crucible are a boiling and seething mass. By this reaction the pure steel is liberated and settles immediately to the bottom of the mold. The crucible is then tapped by striking the tapping pin with a special iron spade and the molten steel runs

into the mold followed by the aluminum oxide and corundum slag. The chemical reaction described is completed in about 30 secs., and in five minutes the molds can be removed.

Molds. The molds are made by baking a mixture of sand and rye flour shaped on models. At first a mixture of one part clay and one part sand was used, but it resulted unsatisfactorily. The molds shrunk and checked badly in baking and required a great amount of careful luting to close the joints. Also the clay was baked like a brick by the great heat of the welded joint and was quite difficult to remove, adding somewhat to the expense. At the suggestion of an old foundryman trial was made of a mixture of clean, sharp sand, with 10% of coarse rye flour; the mixture was moistened just enough to retain its form when pressed in the hand. This mixture proved satisfactory. It came away from the model without adhering, baked without shrinking and was hard enough to stand ordinary handling. By adding a teaspoonful of linseed oil to the mixture for a pair of molds it baked as hard as concrete — unnecessarily hard for ordinary purposes, but most desirable for special molds for broken or combination joints.

The molds are baked in a brick oven having a flat iron plate above the firebox to baffle the heat and above this two racks capable of holding twelve sets of molds. For baking a moderate heat, about the temperature required for baking bread, has proved the most satisfactory; a higher temperature burned the rye flour and destroyed its cementing properties. One man receiving 15 cts. per hour makes and bakes the molds and he can turn out 12 sets every five hours, or 24 sets per day. This gives a cost for labor of about 6¼ cts. per set. The molds actually cost about 10 cts. a set, counting in materials and lost time due to the full output of the oven not being required each day.

Crucibles. The crucibles furnished by the Goldschmidt Thermit Co. cost $7.25 each, but since using up the first six bought the railway company has made its own, buying magnesia tar from the Goldschmidt Thermit Co. at 2½ cts. per lb. The tar is mixed with 25% of old crucible material finely powdered. These crucibles last on an average for about 30 joints. They are baked in the oven previously described with a higher temperature than that required for the molds. The cost of the crucibles is $2.40 each, made up of the following items:

48 lbs. magnesia tin at 2½ cts.	$1.20
12 lbs. old crucible powder, labor	0.15
6 hrs.' labor at 15 cts. molding and baking	0.90
Fuel	0.15
Total	$2.40

Cost of Welding. The welding was done by a gang of 1 foreman and 3 laborers. This gang has never exceeded 20 welds per 10-hour day. The wages paid were: Foreman, $2.50 per day, and laborers, $1.50 per day. The welding portion consists of 16 lbs. thermit and 2 lbs. iron punchings, or 15 lbs. thermit and 3 lbs. iron punchings, if a lower temperature seems desirable. The

total cost of the welding portion, including igniting powder, tapping pin, and plugging materials for crucible, consisting of asbestos washer, iron disc and refractory sand, is $4.25. The cost of welding 100 joints on T-rail 7 ins. high, 6 ins. base and 3 ins. head during 1906 was per joint as follows:

Cost of mold	$0.10
Cost of crucible	0.10
Cost of casting materials	0.20
Foreman	0.25
Laborers	0.91
Thermit portion	4.25
Total	$5.81

To this is to be added $1.63, which is about the average cost of removing and replacing brick pavement at each joint for labor and materials, using old broken stone for concrete and cleaning old paving blocks. This addition brings the total up to $7.44 per joint welded. The cost of welding 600 joints in 1905 on 9-in. tram head rail, including all labor, materials, tools and patterns incident to the work, experimenting with mold materials and cost of oven, was $5.86. The cost of the original outfit for welding was:

1 Automatic crucible	$ 7.25
1 Set mold models	12.00
1 Set mold clamps	6.00
1 Tapping spade	1.00
1 Tripod for crucible	4.00
1 Set mold boxes	2.50
Total	$32.75

Precautions. Certain precautions are necessary to get the best results by the thermit process, and some of these we quote from Mr. French as follows:

"When we began welding this 7-in. rail we found that we could sledge off the welds and that the iron from the thermit compound had not united with the rail; also that the iron came up to the top of the rail head. We subsequently found that the mold models had become mixed, and we had used one of too small horizontal cross-section, and consequently the rail chilled the small volume of molten iron coming in contact with it. Upon enlarging the mold model so that the thermit portion furnished only enough iron to come up under the rail head, we obtained welds that resisted the most vigorous sledging that could be given with a 10-pound hammer. We were able to batter the weld out of shape, but could not separate it from the rail. This sledging test is now applied to all welds.

"We found when welding in the morning with rising temperature that tightly-closed joints often humped up when welded. This proved to be due to the latent compression in the rails that did not manifest itself unil the rail ends became soft. These humped joints were ground down with an emery wheel grinder. We had

only a few of these joints when we realized the cause, and readily prevented such action by welding on cooler days or when the temperature was falling. We obtained the best results with joints open about 1/16 to 1/32 in., the expansion in welding closing tightly such an opening. We have made excellent combination welds between 80-lb. T-rail, 7-in. 70-lb. and 95-lb. T-rails and 9-in. girder rails. In making combination welds we found that it was essential to a get a good body of metal between the upper side of the base of the deeper rail and the under side of the shallower section in order to secure the strongest type of weld.

"Thus far there has been no appreciable excess wear in the head of the rails at the welds and the heated portion seems to take the original temper, as it cools down slowly in about the same way as when coming from the rolls.

"A few portions of thermit, not over six, have been lost through failure of the workman to tap the crucible properly, or lack of luting around the joints of the molds. We have had but one explosion during our entire experience. That occurred after using the process 18 months, and was caused through carelessness in welding on a rainy day and in not thoroughly luting the molds near the top. The slag came in contact with the wet earth around the mold, but aside from the scare occasioned by the report and a slight burn on the foreman's arm from flying slag no harm was done, and the weld turned out to be a good one."

Cost of Cutting Off Steel Sheet Piles with the Electric Arc. F. C. Perkins (Engineering and Contracting, 1907) describes the use of the electric arc in cutting off steel piles at the New Hoffman House foundation work in New York city.

The steel piles being cut are 5/8 in. thick, in the web and 3 ins. at the interlocking points. It is stated that the time required in burning the 5/8-in. steel is four minutes per foot and the time taken at the interlocking points is said to be 8 minutes.

The arc light carbon is held in a metal clamp fastened to a metallic rod and socket, which is in turn bolted to a long wooden pole, the cable conducting the current being flexible and connected to the metal clamp of the carbon terminal. The steel to be cut is connected to the other conductor from the alternating current circuit. The men are protected from the extreme heat and terrific glare by goggles and asbestos masks as well as gloves, as it has been found that the carbon fumes produced by the high power electric arc. affected the lips and other parts of the face and hands.

About 1,200 amperes are utilized at 50 volts pressure, alternating current being employed stepped down to the above voltage from the high pressure service of 2,500 volts. Single phase alternating current is employed, taken from the street service mains, the frequency being 60 cycles per second.

The cost of cutting steel piling with current at 10 cts. kw. and the attendant at 50 cts. per hour, is stated to be as follows per foot of piling cut;

Cost of current	$2.56
Labor	0.40
Total	$2.96

This is rather high, and the hack-saw would probably be cheaper. However, with current at say 3 cts. per kw.-hr. the cost per foot would be but $1.17. Even at this rate, with labor competent to use a hack-saw at 25 cts. per hour, the saw would be the cheaper.

Miscellaneous Oxy-Acetylene Welding and Cutting Costs. The costs in Tables XIII to XV have been accurately obtained. Davis-Bournonville apparatus was used.

TABLE XIII. COSTS OF BUTT WELDING PIPE

Labor at 42 cts. per hour. Oxygen and acetylene at 2 cts. per cu. ft. Welding wire at 10 cts. per pound.

Size of pipe	Labor	Oxygen cu. ft.	Acetylene cu. ft.	Wire	Thickness of pipe	Tip No.	Gas pressures Oxygen	Gas pressures Acety.	Total cost
4-in.	6 min.	2.84	2.49	5 oz.	15/64 in.	6	12 lb.	6 lb.	$0.18
6-in.	12 min.	5.68	4.98	8 oz.	9/32 in.	6	12 lb.	6 lb.	.34
8-in.	16 min.	7.58	6.65	12 oz.	5/16 in.	6	12 lb.	6 lb.	.47
10-in.	18 min.	8.53	7.48	16 oz.	5/16 in.	6	12 lb.	6 lb.	.54
12-in.	26 min.	12.32	10.81	20 oz.	21/64 in.	6	12 lb.	6 lb.	.77
16-in.	42 min.	33.18	29.40	32 oz.	3/8 in.	8	16 lb.	6 lb.	1.75
Average Cost of Cutting Pipe (4 cuts made of each size)									
4-in.	0 625	0.781	0.125		15/64 in.	2	20 lb.	3 lb.	$0.02
6-in.	0.87	1.087	.174		9/32 in.	2	20 lb.	3 lb.	.03
8-in.	1.5	1.775	.3		5/16 in.	2	20 lb.	3 lb.	.05
10-in.	1.77	2.118	.355		5/16 in.	2	20 lb.	3 lb.	.06
12-in.	2.1	2.625	.42		21/64 in.	2	20 lb.	3 lb.	.07
16-in.	3.62	4.531	.725		3/8 in.	2	20 lb.	3 lb.	.13

TABLE XIV. COST OF BUTT WELDING PIPE

Size of pipe	Welding time, min.	Cost of labor placing and turning pipe	Total cost of welded joints	Cost for dresser couplings
2-in. I. D.	3	$0.09	$0.18	† $0.53
4-in. O. D.	6	.165	.34	.69
6-in. O. D.	10	.245	.52	1.29
8-in. O. D.	15	.33	.70	1.49
10-in. O. D.	16	.365	.80	2.09
16-in. O. D.	40	.46	* 2.50	3.89

* Two welders employed.
† The cost of couplings is shown without the necessary labor to install.

The Pacific Gas and Electric Co., with welder at 47 cts. per hr. and gases at 2 cts. per cu. ft., has obtained very low cost in butt welding gas mains of various sizes of pipe, including the labor cost of placing and turning pipe, and makes interesting comparison of the cost of welded joints with the cost of recessed

couplings as formerly employed. The welding was done with portable outfits. See Table XIV.

Cost of Various Oxy-Acetylene Cutting Operation. The costs of miscellaneous work in Table XV were obtained under ordinary working conditions in the field, where continuous operation is frequently impossible owing to other labor involved, or the necessity for moving from place to place.

TABLE XV. COST OF VARIOUS CUTTING OPERATIONS

Hand cutting	No. of cuts	Labor 46 ct. hr.	Oxygen cu. ft.	Acetylene cu. ft.	Total cost	Cost per cut
6-in. I-beams	20	75 min.	28	10	$1.33	$.0665
8-in. I-beams	4	6 min.	8	2	.25	.0625
12-in. I-beams	4	8 min.	16	4	.47	.1175
15-in. I-beams	10	45 min.	40	10	1.35	.1350
15-in. I-beams	1	1 ft. 23 in.	3	1	.092	.092
5-in. T-rails	20	75 min.	37	12	1.55	.0775
8-in. T-rails	4	10 min.	20	6	.60	.15
9-in. street car rails	10	45 min.	40	10	1.35	.135
12-in. Lackawanna piling	88	9½ hrs.	350	60	12.57	.143
3/16-in. boiler plate	40 ft.	60 min.	20	2	.90	.0225 per ft.
½-in. boiler plate	55 ft.	130 min.	130	40	4.72	.086 per ft.
1-in. boiler plate	80 ft.	150 min.	250	56	7.27	.091 per ft.
¾-in. web of rail	33 ft.	50 min.	90	13	2.45	.074 per ft.

Cost of Oxy-Acetylene Welding of Pipe. Under ordinary conditions, it is stated in Engineering News, Feb. 4, 1915, a skillful operator can weld in an hour about one joint on 12-in. pipe and from three to five joints on 4-in. pipe. The cost is said to be from 25 to 40% less than that of a recessed screw joint, including the cost of the coupling and its application.

With the welded pipe, the branches, laterals, drips and various other fittings are made integral parts of the continuous main, while with screw-joint pipe they are separate and special parts whose numerous joints are often a source of trouble. Laterals are inserted at any point by cutting a hole in the main (with the cutting blowpipe) and welding in the end of the lateral. The only material required to make up these specials are odd lengths of pipe of the required sizes, which can be cut and connected at any point and in any way. The cost of making the Y, with two 8-in. pipes connecting to an 8-in. main, is about 76 cts., as given in Table XVI.

A great advantage of such continuously welded mains is that leaks from the joints, always a large source of loss in every gas distribution system, are wholly prevented. Thus these mains are especially advantageous for natural gas and oil pipe lines as well as for city gas distribution. For ammonia, and other refrigeration systems, elimination of leakage is important for safety as well as economy.

Certain cost figures compiled by the makers of the Oxweld ap-

TABLE XVI. COST OF WELDING PIPE JOINTS AND YS

	6-in. pipe		16-in. pipe	
Labor, 30 cts. per hr.	20 min.	10 cts.	90 min.	$0.45
Oxygen, 2 cts. per cu. ft.	10 ft.	20 cts.	40 ft.	0.80
Acetylene, 2 cts. per cu. ft.	9 ft.	18 cts.	36 ft.	0.72
Filling wire, 12 cts. per lb.	¾ lb.	9 cts.	2 lb.	0.24
Total		57 cts.		$2.21

	8 x 6-in. Y			
	Cutting		Welding	
Labor, 30 cts. per hr.	3 min.	1.5 cts.	22 min.	11 cts.
Oxygen, 2 cts. per cu. ft.	3 ft.	6.0 cts.	12 ft.	24 cts.
Acetylene, 2 cts. per cu. ft.	1 ft.	2.0 cts.	10 ft.	20 cts.
Filling wire, 12 cts. per lb.	....	......	1 lb.	12 cts.
Total		9.5 cts.		67 cts.

paratus used in Chicago are as follows: For 4-in. butt-welded pipe, 43.5 cts. per joint. The segregation was 15 mins. labor, 7.5 cts.; 8 cu. ft. oxygen, 16 cts.; 7 cu. ft. acetylene, 14 cts.; ½ lb. filling wire, 6 cts. Six-in. pipe welds cost 57 cts. each; 8-in., $1.055; 12-in., $1.57, and joints for 16-in. pipe, $2.21. For the last named pipe 1½ hrs. of labor cost 45 cts.; 40 cu. ft. oxygen, 80 cts.; 36 cu. ft. acetylene, 72 cts., and 2 lbs. filling wire, 24 cts. An 8-in. pipe was welded into an 8-in. main to form a tee at a cost of $3.04. A 6-in. 60-deg. Y required 10 mins. to cut and 45 mins. to weld. The total cost was $2.14.

Cost of Oxy-Acetylene Welding in an Electric Railway Shop. L. M. Clark (Electric Railway Journal, Jan. 4, 1913) gives in Table XVII the cost of welding in an electric railway shop in Indianapolis:

TABLE XVII. COST OF OXY-ACETYLENE WELDING IN AN ELECTRIC RY. SHOP

Name of part	Amount of Material Oxy.	Acet.	Filler	Time, hours	Cost of welding
Motor axle cap	5	3	1	1	$0.48
Armature housing	5	3	1	1	0.48
End bearing for mixer	190	104	5	10	9.44
Cutting anti-climber	30	18	..	2	1.43
1 bumper iron	70	42	1½	3	3.02
1 journal box, 5 x 90	90	54	2	5	4.40
1 brake valve body	'10	6	½	1	0.67
1 scissors	5	3	½	1	0.52
6 motor axle caps	30	18	1	3	1.75
1 motor frame	340	204	5¾	20	15.92
1 magnet frame	20	12	½	2	1.23
1¾ x 7 journal box	50	30	1	3	2.58
Peck. truck side frame	170	102	2	12	8.40
Peck. truck frame	150	90	1½	10	7.25
6 motor axle caps	30	18	1	3	1.75
5 Lorain compressor shells	100	60	2	7	5.26
1 5 x 9 journal box	40	24	1	2	1.95
1 door sheave	20	12	Brass	1	1.04
5 motor caps	35	21	1	3	1.91
1 Peck. truck side frame	190	114	2¼	10	8.56
Cam for stoker engine	45	27	5	2	2.43
1 armature shaft	280	178	3	11	11.73

Name of part	Amount of Material Oxy.	Acet.	Filler	Time, hours	Cost of welding
1 truss rod anchor	15	9	1	1	0.79
Heating 2 tires	15	9	..	1	0.72
Standard truck frame	220	132	3¼	11	9.82
1 pipe vise	5	3	½	1	0.52
Annealing wheels	30	18	..	2	2.42
Steam trap	20	12	1	1	1.02
Coal elevator cam	40	24	1½	3	2.25
Side frame on truck	215	129	2½	12	9.84
Cut hole in boiler	30	18	..	4	2.20
3 coal elevator cams	140	84	3½	5	6.37
Cut 6-in. I beam	15	9	..	..	0.72
Peck. truck side frame	175	105	2	4	6.56
Westinghouse top motor frame	400	240	4	20	17.16
I beams cut-off	50	30	..	2	2.00
Westinghouse pinion axle cap	100	60	4¼	7	5.25
Peckham truck frame	250	150	4	15	11.39
Peckham truck frame	50	30	½	5	2.72
Anti-climber castings cut	50	30	..	2	2.00
Westinghouse pinion axle cap	100	60	2	10	5.74
Westinghouse top motor frame	400	240	7	20	17.36
Westinghouse pinion axle cap	150	90	3	10	7.10
Peckham truck frame	150	90	3	15	8.23
Loraine bottom motor frame	100	60	2	3	3.91
Westinghouse top motor frame	400	240	4	20	17.16
Westinghouse top motor frame	140	84	3	12	7.24
Westinghouse motor frame	450	270	5¾	15	18.48
Westinghouse top motor frame	300	180	4	18	13.61
Anti-climber castings	50	30	..	2	2.00
4¾ x 7 Symington fire boxes	350	2.10	5¾	15	15.38
Westinghouse compressor gear case corer cap	25	15	1	3	0.68

Speed of Cutting with Oxy-Acetylene Torch. J. M. Morehead in a paper before the New York Railroad Club gives the Table XVIII of cutting speeds attained in ordinary practice.

TABLE XVIII. CUTTING SPEEDS

Thickness of steel	Heating jet feet of acetylene	Heating jet feet of oxygen	Cutting jet feet of oxygen	Pressure of oxygen heating jet, lbs.	Pressure of oxygen cutting jet, lbs.	Lineal ft. cut per hr.
Up to ½ in.	12	15½	60	14–18	125	50
½ in. to 1½ in.	12	15½	75	14–18	125–150	30

While very desirable in welding, in cutting it is quite essential that the oxygen be pure. If any appreciable amount of nitrogen is present, this nitrogen expands with the heat and prevents the acetylene from entering the slot. This results in a wide kerf and unsatisfactory work, while at the same time the amount of oxygen necessary for any given work increases enormously. Table XIX shows how the quantity of oxygen necessarily varies with its purity. It will be observed that with oxygen containing

TABLE XIX. TESTS ON CUTTING POWER OF OXYGEN OF VARYING PURITY ON MILD STEEL PLATE ¾-IN. THICK

Test No.	1	2	3	4	5	6	7	8	9
Purity of oxygen used	99.3	98.0	97.6	96.8	96.4	95.0	92.0	87.3	83.3
Time in seconds occupied in cutting..	272	286	295	360	363	377	551	660	855
Total length of cut in inches	67⅞	67½	67⅞	68¼	67½	67½	67½	67½	67⅞
Total oxygen used, cut. ft............	7.5	9.1	9.8	11.8	11.3	11.6	15.0	16.2	18.9
Oxygen used per foot run	1.3	1.6	1.7	2.1	2.0	2.1	2.7	2.9	3.3
Time occupied per foot run...........	48	51	52	64	64	67	98	117	153
Per cent. increase in oxygen consumed	Taken as unit	23%	31%	54%	61%	61%	108%	123%	154%
Per cent. increase in time occupied.		6%	8%	33%	33%	39%	104%	144%	214%

The appearance of the cuts were as follows: (1) Very good. Like hot saw cut. (2) Good Cut. (3) Fair cut — rather rough. (4) Fair cut — rather rough. (5) Ragged and cindery. (6) Ragged and blowing back. Dirty and cindery. (7) Very dirty and rough. (8) Blew back badly Very rough cut. (9) Very rough and slaggy. Not properly cut through.

18% or more of impurities it is practically impossible to do satisfactory cutting work.

Costs of Various Acetylene Operations. E. F. Eggert (Autogenous Welding, July, 1914) gives the cost of cutting out numerous small parts used in ship construction. Pieces Nos. 1 and 3, Fig. 4, are examples of the anglesmith's art, only they were made by an acetylene operator; No. 1 is the boxed end of a staple angle, used in making a deck or bulkhead water tight, where a Z-bar passes through it; and No. 3 is an angle corner with the flange of the angle turned outward, used in bounding decks and bulkheads to form connections and make them water-tight. An

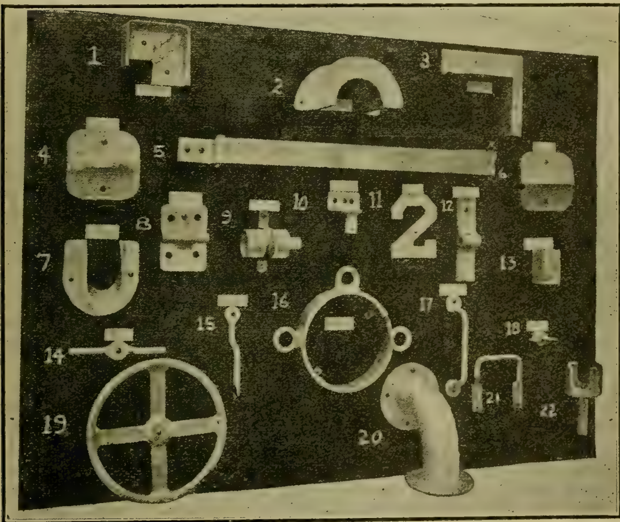


Fig. 4. Miscellaneous parts made with an oxy-acetylene torch.

anglesmith, in making No. 1, has to take a long heat, cut V-shaped sections out of the flange, bend the web twice, as near to the proper point as he can, dress the job to get the dimensions right, and then make two welds in the flanges. The acetylene operator makes one V-shaped cut in the flange, and removes the end of the flange; this with the cutting torch and to exact dimensions. Then he draws his torch along the line on the web where the angle should be bent, gets it hot, and it bends as easily as copper wire; the dimension is correct and the corner square without dressing. After making the second bend, he makes two straight-line welds in the flange, and the job is done. In a 2 by 3-in. angle, this job costs about 50 cts.; the welds are sound and will stand

any amount of hammering to prove it; the under surface is smooth, so the flange can be calked water-tight. Piece No. 3 is made in the same way, save that a square insert is welded in the flange, needing two straight-line welds. Cost about 30 cts., including cost of cutting the square insert.

Pieces Nos. 2, 5 and 10 go to make hose and nozzle racks for ship-board installation. The hose is hung over No. 2, being held to the bulkhead by No. 5, consisting of two clips, riveted or tap-bolted to the bulkhead; the strap is hinged to the one on the left, and pinned to the one on the right. By taking out the pin, the strap swings clear and the hose can be removed. The orifice of the brass nozzle slips over the downward projection of No. 10, and its base rests on a simple angle clip.

In making No. 2, circular rings are cut on the pantograph machine; a piece of pipe is cut to length; the rings are cut in two, the pipe split lengthwise, and a half ring welded to the end of each half pipe. This costs about 80 cts. much less than a casting.

The clips of No. 5 are cut from bar steel, and bent as described above; the strap is cut from the same bar. The hinges are made of ½-in. extra-heavy iron pipe, each hinge of three pieces; the strap and clips being laid together lengthwise; the three pieces of pipe for each hinge, held together by a bolt running through them, are laid in place and tacked there by the welding torch. Then the two bolts are removed, disassembling the clips from the strap, and the welding of the pipe completed. This saves expensive forgings and the machining thereof, and costs only 90 cts.

The nozzle keeper, piece No. 10, consists of a short piece of ¾-in. extra heavy iron pipe, welded to a little angle clip; it avoids a casting, and costs only 30 cts.

Pieces Nos. 4 and 6 are pad eyes; eyes made parts of pads which are riveted to a deck or a bulkhead for a tackle, or brace, to hook into or secure to. The eyes are not completed in these samples; they would be formed by punching or drilling. These pad eyes were made by cutting them from scraps of T- or I-bars, finishing by knocking off the rough on a grinder. Thus, forgings are avoided, and pad eyes produced at 10 cts. each. If a thicker eye is wanted, it can be formed by welding two pieces of angle bar back to back.

Piece No. 7 is a scupper lip, secured under a pipe discharging over the side to throw the water clear of the side, so as not to streak it. It is formed of two pieces of plate, cut to proper shape; the lip is then bent to shape and welded to the flange. This method obviates a casting, and the scupper lip costs 80 cts.

Piece No. 8 is a hinge, made of two pieces of plate and a piece of ½-in. extra-heavy iron pipe. The pipe is cut in three pieces, the pieces being held together by a bolt slipped through them; the two pieces of plate are laid edge to edge, the pipe laid lengthwise on the crack, and then welded. This saves two forgings, or castings, and the necessary machining, the hinge costing 45 cts. This is, of course, a special, heavy hinge, and is not a commercial

article; and usually these special fittings are wanted in a big hurry.

No. 9 is a stanchion foot, cut from the end of a stanchion. It is made of 2-in. pipe, to the end of which is welded a ¾-in. washer; and on the washer is welded a piece of ¾-in. extra-heavy pipe. In quantities, this is a forging-machine job, requiring dies, and is by no means cheap; in small lots it is a hand-forging job. With the torch, it costs 15 cts.

Piece No. 12 is another hinge, a very heavy one, made by cutting two pieces from the web of a bulb angle or T-bar. Then the pieces are cut to mesh together, and a hole drilled through the bosses thus formed. All the cutting is done with the torch. It makes a very strong hinge, saving forging and machining, and costs but 40 cts.

Piece No. 13 is a stanchion or batten clip; riveted to the deck, it receives and holds in position the bottom of a stanchion or batten used in a storeroom, or magazine, to hold stacked packages in place. It is made of a piece of U-bar with a piece of plate welded across the end; it avoids expensive anglesmithing, or a casting, and costs but 10 cts.

Pieces Nos. 14, 15 and 17 are quite similar, being made of ½-in. round bar, bent in the vise, and welded to 1½-in. punchings. No. 14 is a wing nut, costing 20 cts.; No. 15 is a dog handle, costing 10 cts., and No. 17 is a grab rod, costing 15 cts. In large lots these are jobs for the drop hammer, or the forging machine; but in small lots of special sizes the torch price is pretty low.

The mast band, piece No. 16, would ordinarily be made by a smith; he would roll up the ring and "jump on" the three eyes. In this case the acetylene operator rolled up the bar cold, and welded it together; then welded on the eyes. The eyes to the left and right are the heads of two shouldered eyebolts; but to show that he is independent of the stock of eyebolts, the top eye was formed of a piece of ½-in. round. This job cost only 60 cts.

Piece No. 18 is a butterfly nut made by welding two thin 1-in. punchings, to an ordinary ¾-in. nut, smoothing up the job by adding metal. It met a hurry-up requirement, and cost only 15 cts. for the one.

The handwheel, piece No. 19, shows how an emergency job can be quickly done; a piece of scrap plate was cut to form the spokes and hub, a 1½-in. washer welded to the hub to form a boss, and a piece of ¾-in. round was bent, welded together and welded to the spokes to form the rim. It saved a casting, and cost $1.50, less than the pattern would cost.

The 3-in. elbow, Piece No. 20, was a sort of exhibition job; it is made of plate, every section being cut, rolled and welded; the flanges were also cut with the torch. It cost $2.24, and so is not very economical; but it is a good-looking job and a strong one, and may be a good thing to know in an emergency.

No. 21 is a steel bucket handle, made of ½-in. round and two pieces of plate; and at 15 cts. is pretty cheap.

Piece No. 22 is a claw wrench, fitted over the spokes of the handwheel of a valve; the rod is extended to a remote and usually higher place, universal joints taking it around corners, and its purpose is to make it possible to operate certain valves from a distance. The claw is made from 3-in. iron pipe; a piece of ¼-in. plate cut out round, is welded to the end of the claw, and the whole then welded to a 1-in. rod. It cost $1.35, and is much cheaper than the forging previously used.

Cost of a Davit Collar and Pump Repairs. When cutting openings in steel plate F. G. Coburn (American Machinist, July 23,

Fig. 5. A Davit Collar made with an oxy-acetylene torch.

1914) states that some operators first drill around, then the torch operator's job is to cut the edges straight. The proper way to do the job is to cut it with the torch in the first place, using a motor-driven torch. The cut will look as if it had been planed. The cut can be made in less than one-tenth the time necessary to drill it.

There are some cutting jobs that are so complete that the smith is eliminated altogether. In Fig. 5 is shown the rough forging of a davit collar. It is hardly right to call it a forging, for it was not forged, but the term will answer, as it is in about the same condition as the smith would put it for the machine shop — except that there is slightly less finish to remove — a scant ⅛ in. This collar was cut directly from the billet in 15 minutes.

The excess material is in three large pieces, which can be utilized in the forge shop; hence, there is no material waste. A smith could not make a good start on this job for what it cost complete by the torch.

Cost of Making Ascetylene. The ordinary charge for carbide in ton lots is $70, or 3½ cts. per lb., and 25 cts. per hundred would deliver it at most points, but we will add 50 cts., which would make the total cost 4 cts. per lb.

A pound of good lump carbide will yield 4½ cu. ft. or more of acetylene. This would make the acetylene cost a little less than 0.9 ct. per ft. Suppose we add the 0.1 ct. for the work of generation and call the cost 1 ct. per ft.

Handling Scrap by Magnets and Locomotive Cranes. The following from Railway Electrical Engineer, October, 1915, gives costs with crane magnets:

In railroad work, the field of application of crane magnets is rather limited. They are at the present time used principally in scrap yards, around store-room platforms, etc., where it is necessary to handle iron and steel rapidly and economically. For this class of work, magnets are generally used in connection with locomotive cranes, making a self-contained, self-propelled unit which may be operated over shop and yard tracks as required. The use of this combination has reduced very greatly the cost of handling both new and scrap material, both by reducing the actual expense of handling and by enabling the material to be handled much more rapidly. In this connection a few examples may be cited. One road has handled with a locomotive crane and magnet 41 tons of old locomotive grates in 40 mins., 56 tons of old track spikes in 33 mins. and 44 tons of miscellaneous scrap in 35 mins. Another road is handling this class of material at a cost of less than $0.02 per ton as compared with $0.25 to $0.35 by hand. A road using four cranes, three equipped with magnets and one with a clam shell bucket, is handling scrap at $0.05 per ton. Specific figures given by one road are as follows:

Kind of scrap.	Crane cost	Hand cost
No. 1 wrought iron	$0.04	$0.22
Busheling, No. 2 wrought iron, and malleable iron	.02	.10
Cast iron and mixed steel	.02	.09
Sheet steel	.20	.30

On some roads where traffic is very dense, a locomotive crane with magnets is used to pick up and load scrap along the line. The scrap, consisting of old rails and other track supplies, is collected and put into small piles along the track by the section gangs; a locomotive crane with a magnet is then sent over the line in a work train, thus handling the scrap cheaply and rapidly.

In shop work, cranes are also used to a limited extent, for handling parts such as car-wheels, castings, etc.

As can be seen from the foregoing, crane magnets will be used on outdoor work practically altogether. This requires that the construction of the magnet be such as to be unaffected by weather

conditions, as reliability is a prime factor in economical operation. The failure of a magnet will, in most cases, seriously cripple the section of the yard where it is in use. All of the manufacturers of magnets now on the market have apparently taken this point into consideration and are using very rugged construction, so that the magnets are practically indestructible.

Another very important point in magnet construction is that of insulation; due to self induction the voltage impressed on the magnet may, at the time the circuit is opened, rise to four or five times normal, thus setting up stresses which may break down the insulation in case it is in any way defective. In some makes of magnets this inductive discharge is shunted through a resistance, by means of suitable contacts in the controller. This is a desirable feature as it eliminates the high voltage and reduces the strain on the coil insulation.

Direct current is, of course, essential to the operation of crane magnets. They are usually wound for 220 volts, although 110 volt magnets may be obtained. The operation of magnets from 550 volt circuits is not recommended, due to the high voltage induced at the time the circuit is opened, even when discharge resistance is connected in circuit.

The controllers used in connection with crane magnets are of simple construction. They may be either of the magnetic or of the drum type. Three operating points are usually provided, these points being—"lift," "drop" and "off." When the control handle is placed in the lifting position, the magnet is connected across the line, thus energizing it and enabling it to pick up the desired material. When the handle is thrown to the drop position, the current through the magnet is reversed, thus giving an instantaneous re-release and effecting a slight saving in time by eliminating the sluggishness of release which is sometimes found when handling pieces which completely span the magnetic poles, or parts consisting of hard steel which retains a considerable amount of residual magnetism. In the off position, the magnet is dead.

The controllers are usually arranged so that the handle will not remain on the "drop" point, a spring being provided which throws the handle to the off position as soon as it is released by the operator.

Where magnets are used in connection with traveling or locomotive cranes operated by direct current, power can, of course, be taken from the crane supply circuit. On steam operated locomotive cranes, a small engine or turbine driven generator supplies the necessary direct current for the magnet, although power may in many cases be taken from a shop circuit through receptacles located at convenient points. Where the area to be covered by the crane is small, the connection to the supply circuit can often be made permanent, a flexible cable of suitable length being used.

The life of this cable, as well as of that connecting the magnet to the controller, may be materially increased by the use of some

automatic device for taking up slack. One manufacturing company builds a simple motor driven take-up which has proved very satisfactory in operation.

In general, the information obtained indicates that the cost of maintenance on crane magnets is practically negligible and consists, in most cases, simply in the renewal of cable. Where power for operating the magnet is supplied by generating equipment mounted on the crane, there will be also some slight maintenance expense for this apparatus. The simpler construction of the small steam turbines driven set as compared with engine driven equipment would seem to make the former somewhat preferable, as requiring less attention. This is especially the case in view of the fluctuating nature of the load on the generator.

In addition to the circular type, which is in most general use in railroad work, other forms of magnets are obtainable, arranged for handling special material. Among these types are the flat magnet for handling plates, the bi-polar type for handling rails, rods, pipes, etc., also magnets with specially shaped pole pieces for handling material such as car-wheels. However, the circular magnet will be found the most generally useful and it will take care of practically any class of work.

The use of magnets undoubtedly constitutes the simplest and cheapest method of handling iron and steel, and your committee suggests that the members of our association familiarize themselves with this class of apparatus, with a view to applying it to a greater extent than has been the case up to the present time.

Ratio of Average Load to Connected Load. A. M. Dudley (Transactions of American Institute of Electrical Engineers, Mar. 10, 1911) states that users are apt, in figuring their power consumption, to take the capacity from the name plate of the driving motor or motors and consider that as the average consumption. If, as is more often the case than not, this unit has been liberally allowed for, the ultimate calculated consumption of power is in error by even more than the ratio of the maximum to the average consumed. When these facts are considered, it is not so hard to understand why the cost of power is sometimes figured in error by 400%. As an illustration of how serious this error may be, figures are submitted showing the ratio of the *average load* to the *connected load,* which are the result of a number of observations and fairly represent the average condition. These figures are as follows:

	Per cent.
Cement mills	85
Textile mills, cotton and woolen	75 to 80
Tanneries	55
Ice machines and refrigerating plants	53
Marble works	51
Flour mills	50
Carriage and wagon works	35
Machine shops	35
Breweries	33
Boiler shops	28
Sheet metal manufacturing	27

	Per cent.
Soap manufacturing	28
Rubber manufacturing	25
Wood working	10 to 35
General average of all industries (approx.)	33⅓

See the latter part of Chap. I where load factors are discussed.

First Cost and Maintenance of Portable Batteries for Automatic Signals. A detailed account of the operation of these storage batteries is given in a paper read before the Railway Signal Association March 20, 1911, by A. H. McKeen, signal engineer of the Oregon-Washington Railroad & Navigation Co., and of the Southern Pacific Co. lines in Oregon.

The methods of transportation to and from the charging plants vary with local conditions. On portions of the line where local passenger service is available, the batteries are loaded into the baggage car and distributed at each station by the batteryman, who accompanies the batteries. From the stations they are taken to the various battery locations by the maintainer on a velocipede or motor car, the discharge batteries being returned in the same manner to the station, where they are picked up by the batterman and brought back to the charging plant on the return train in the evening. On other sections of the line the batteries are loaded into a specially arranged battery car and handled on local freight trains, stops being made at each battery location, where the batteries are changed by the batteryman and the maintainer on that district. The car containing the discharged batteries is sent back to the charging plant on the first freight train. Another arrangement consists of a charging plant built in a box car, which car is moved on the daily way freight and is set out at each alternate station; in one end of the car is located the gasoline engine, generator, switchboard, and cooling tank. A large gasoline tank holding sufficient gasoline for one month's supply is suspended under the body of the car. The center part of the car is used as a battery room and is suitably fitted up with a battery bench, lead-lined sink and a large water tank for battery washing purposes. The other end of the car is arranged as living quarters for the batteryman. The car is equipped with heavy draught gear in order to avoid any damage due to rough handling while in transit. During the three years that this portable arrangement has been in service, it has given the best of results, handling on one district, 832 cells monthly on a territory of 150 miles of single track signals. An important advantage in this method is that on the 150-mile district referred to, only 80 extra cells are required for changing out purposes; this being only 10% of the total number of cells in service on the district.

On the Harriman Lines there are 52 charging plants; each of which (except the portable plants) is located at the headquarters of the assistant supervisor, where a shop building is provided. Since part of this shop building is used to house the charging machinery no special building is necessary. The average territory covered by each plant is 104 miles. Wherever current

can be obtained from local power companies, a mercury arc rectifier or motor generator set is installed, and at other locations where electric power is not available a gasoline engine and generator charging outfit is used. Each charging plant is in charge of a special batteryman, whose duties consist of charging, inspecting and cleaning the batteries and assisting the maintainers in changing out the cells on their districts. All cells are returned to the plant monthly and are thoroughly inspected and cleaned before being put on the charging circuit. A record is kept in a book, provided for the purpose, of the voltage, specific gravity and condition of each cell on arrival at the plant and each cell is examined for short circuits and other faults; the hard rubber covers and connectors being cleaned and sediment removed if necessary. Once a year the old electrolyte is replaced with new in order to discard all impurities held in solution.

In the case of stationary batteries it is the usual practice to give an overcharge several times a month, the overcharge having the effect of driving the sulphate out of the plates and keeping them in a healthy condition. Portable cells which are charged once a month only, are subject to considerable sulphating and therefore require a long charge to bring them up to capacity. It is the practice to continue the charge for two or three hours after the voltage and specific gravity has ceased to rise. The uniform gassing of all cells on charge is a good indication of their condition and the failure of any cell to gas is investigated before the charge is continued. During the charge, voltage and specific gravity readings are taken and recorded in the book and any cells not coming up to the proper voltage and gravity are closely watched and given special treatment if necessary. Maintainers are required to make weekly inspection of all cells in service, examining them for loose connections, taking voltage readings and replacing any evaporation of electrolyte that may occur during the time the cells are in service. In replacing the evaporation, only water whose purity has been previously passed on is used. In localities where pure water is not obtainable, distilled water is provided.

In charges subsequent to the initial charge the general rule is that the amount of current put into the cell should be twice the amount delivered by the cell during the 30 or less days elapsing since the previous charge. Under normal conditions and service the amount of current required of a cell will vary from 46 to 75 ampere hours per month.

The batteries are housed in the lower case of the signal, which makes them easily accessible for inspection. The lower signal case also serves to accommodate the track and line relays. At the end of sidings on single track or other locations where two signals are opposite each other, one set of batteries is used to operate both signals. After the batteries have been in service fifteen days, the maintainer interchanges them with the batteries of the distant signal, this having the effect of equalizing the discharge to a considerable extent on all cells in service. It also

avoids the necessity of charging cells for different lengths of time on their return to the charging plant and eliminates the possibility of cells being discharged to a point that might result in a signal failure.

COST OF STORAGE CELLS

1 cell SS-7 storage battery complete	$4.85
2 battery connectors, at 8 cts. each	.10
Electrolyte	.03
Freight charges	.30
Total cost	$5.34
Cost of charging machinery and apparatus in 52 plants, at $450.00 each	$ 23,400.00
Cost of 48,516 storage cells, complete, including freight charges	259,075.44
Cost of 12,129 carry cases, at $2.60 each	31,535.40
Total cost	$314,010.84

COST OF PRIMARY CELLS

1 350-ampere-hour primary cell, complete	$2.00
Freight charges	.20
Total cost	$2.20
Cost of 178,480 primary cells, complete, including freight charges	$392,656.00
Cost of 9,026 concrete battery wells, at $25.00 each	225,650.00
Freight charges on 9,026 concrete battery wells, each weighing 1,600 lbs., at $20.00 each	180,520.00
Charges for work train and locomotive crane or derrick with crew for unloading and placing 9,026 battery wells, 90 days at $50.00 per day (estimated)	4,500.00
Cost of labor for digging holes and setting 9,026 battery wells at $10.00 per well (estimated)	90,260.00
Total cost	$893,586.00

COST OF MAINTENANCE OF STORAGE CELLS PER YEAR

Interest on investment of $314,010.84 at 5 per cent	$ 15,700.54
Depreciation on 52 charging plants costing $23,400, at 10 per cent.	2,340.00
Depreciation on 48,516 positive groups costing $1.57 each, at 22 per cent.	16,757.43
Depreciation on 48,516 negative groups costing $1.835 each, at 25 per cent	22,256.71
Depreciation on 12,129 carrying cases costing $2.60 each, at 10 per cent.	3,153.54
Cost of renewals of broken jars, covers and separators on 48,516 cells at 9 cts. per cell per year	4,366.44
Cost of electrolyte renewals on 48,516 cells at 3 cts. per cell, per year	1,455.48
Cost of current, gasoline, oil, etc., at charging plants per year at 18 cts. per cell	8,732.88
Total cost	$74,763.02

COST OF MAINTENANCE OF PRIMARY BATTERIES PER YEAR

Interest on investment of $893,586, at 5 per cent	$ 44,679.30
Cost of renewals for 178,480 cells, per year at $1.00 each	178,480.00
Cost of renewals of broken jars and covers on 178,480 cells per year, at 7 cts. per cell per year	12,493.60
Total cost	$235,652.90

With reasonable care, the average life of SS-7 portable cells and their component parts are found to be as follows:

Positive elements	4½ years
Negative elements	4 years
Rubber jars	10 years
Rubber covers	10 years
Rubber separators	10 years
Wood separators	2 years
Carrying cases	10 years

No charges are made for transporting storage batteries either when handled on passenger or freight trains; and even though a nominal charge should be assessed, the amount would not exceed the freight charges over foreign lines for renewals for primary batteries. This item is therefore not included in the foregoing cost of maintenance of storage or primary batteries; neither is the expense for labor for charging, inspecting and changing out storage cells or making renewals to primary cells taken into consideration, for the reason that so far as it can be ascertained from Western roads using primary battery, the cost for labor for maintaining primary batteries is practically the same as with portable storage battery. The batteryman looks after the charging of the storage batteries on a district averaging 104 miles, the maintainers assisting in distributing the batteries, which requires on an average two days time of each maintainer monthly. Maintainers' districts range from 14 to 20 miles according to the number of signals, local conditions, etc. The average district is approximately 16 miles with 32 signals. Maintainers have no helpers and are required to look after all work in connection with the maintenance of signals on their district, including the care of signal lamps.

The prices as shown for both portable storage batteries and primary batteries are the regular list prices less the usual trade discount. The freight charges are figured on an average basis for the entire system and are reasonably accurate.

The cost for current for operating motor-generator or arc-rectifier plants varies from ½ ct. to 5 cts. per kw. and the cost for generating current with gasoline engine-generator sets is about 10 cts. per kw. Taking an average for the entire system the annual cost for charging current is 18 cts. per cell.

Cost of Electric Riveting. The cost of riveting with Eveland electric riveters in which alternating-current energy is used only to heat the rivets, the heads being formed by a single manual operation, is given in Electrical World, Mar. 14, 1914. The figures are based on actual tests with rivets of ordinary length and represent only the cost of energy at 10 cts. per k.w.-hr.

Rivet diameter, ins.	Energy cost per 1,000
0.25	$0.04 to $0.05
0.3125	0.08 to 0.10
0.375	0.12 to 0.14
0.5 to 0.625	0.20 to 0.25

Larger sizes can be riveted at a cost practically proportional to their volume. The labor cost is low with the electric riveter, as one man with a helper can do more work than two men and a forge attendant using pneumatic or other power apparatus.

Cost of Thawing Water Pipes by Electricity. On the basis of 125 house services thawed by electricity in Rutland, Vt., in February, 1904, the cost of the thawing per service was as follows:

Electricity	$1.68
Labor	1.85
Teams and drivers	.58
Total	$4.11

On the average 17 amps. of alternating current at 2,200 volts were required, and at 10 cts. per k.w.-hr. the current cost was $1.68, as shown above. The average time consumed was 27 mins.

Cost of an Electric Sign. An electric sign installed over the entrance to the Grays Harbor Railway & Light Company's branch office at Hoquiam, Wash., is described in Electrical World, Oct. 21, 1916, as strictly a home product, the designing, construction, painting, wiring, etc., having been done by local workmen. The sign measures 8 ft. high and 10 ft. long with white letters 16 ins. high on a blue-black background and is very legible during the day as well. The letters are not of rough construction, the sheet metal was cut out according to design, suitable holes were punched to allow the insertion of the sign receptacles, the wiring was then done, and the two sides were finally bolted onto a wooden frame made of 2- by 4-in. timber and the sign was ready for the painter.

It reads as follows: "Electric Power, Light — Electric Power — Electric Light," and then all out and then all on again and starts the cycle over.

The cost of this home-made 284-lamp sign was as follows:

Sheet-metal work — construction	$ 19.05
Wiring receptacles, etc.	63.32
Painting	15.00
Hanging, etc.	15.14
Lamps	54.18
Flasher	39.99
Transformer	17.00
	$223.68

Power Required for Motor-Driven Farm Machinery. Since most farm operations are essentially seasonable in character special motors are not usually required to drive each particular machine. Advantage has been taken of this diversity by a number of farm owners who have electrical installations by mounting one or more motors on skids or trucks so that these portable units can be moved about to operate machines in the various barns, stables and fields. The motors are provided with runs of cables ending in plugs which can be attached to fused connection blocks mounted at convenient points about the farm.

The University of Illinois Experiment Station, Urbana, Ill., made

tests in 1912 with the assistance of the General Electric Company's staff, to determine the energy consumption required to thresh various grains. The threshing machine used had a 28-in. cylinder and a 42-in. separator and was driven by a 15-h.p. motor. While the energy required to thresh a bushel or volume-measure of grain was found to vary greatly, the consumption in terms of tons handled was fairly constant. The results obtained are reproduced herewith in Table XX.

TABLE XX. ENERGY CONSUMPTION TO THRESH GRAINS

Kind of grain	Yield per acre: Tons of grain and straw	Yield per acre: Bushels of grain	Kw.-hr. to thresh 1 ton	Kw. hr. to thresh 1 bushel
Oats	1.99	73.6	2.62	0.070
Barley	2.27	49.9	2.36	0.108
Wheat	1.97	27.9	2.27	0.160

Table XXI lists the sizes of motors recommended for operating standard farm machines. A single-hole sheller with a sacker attachment, driven by a 1-h.p. motor, requires about 0.025 k.w.-hr. to shell a bushel of corn, shelling at the rate of 26 bushels per hr. Test of a 25-bushel grain elevator capable of unloading 25 bushels of corn in 3 mins. has shown that 45 bushels can be elevated 19 ft. at an energy consumption of 0.1 k.w.-hr.

TABLE XXI. SIZES OF MOTORS TO DRIVE FARM MACHINES

Machines	H.p.	Machines	H.p.
Feed grinders (small)	5	Grain graders	0.25
Feed grinders (large)	15	Grain elevators	3
Ensilage cutters	15-20	Concrete mixers	5
Shredders and huskers	15	Hay hoists	5
Threshers, 19-in. cylinder	15	Root cutters	2
Threshers, 32-in. cylinder	40	Cord-wood saws	5
Corn shellers, single-hole	1	Wood splitters	2
Power shellers	15	Hay bailers	7.5
Fanning mills	0.25	Oat crushers	5

Comparative Costs of Gas and Fuel Oil in Heating Japanning Ovens. E. F. Lake in Machinery, Aug., 1916, describes the methods in use for handling and japanning springs in the factory of the Jackson Cushion Spring Co. A method of heating the japanning oven with fuel oil is described and its cost is compared to the cost of heating with gas, which had previously been used.

Method of Using Fuel Oil. In the construction of the oven, the heat is not applied directly to the work, as in heat-treating furnaces, but pipe coils are laid in the bottom of the oven and the oil flames are sent through these. In this way the ovens are heated by radiation, much as steam radiators are used for heating. The purpose of this arrangement is to prevent any of the products of combustion from entering the baking compartment to discolor,

dull or otherwise ruin the smooth, glossy surface of the japan. Furthermore, the currents of air are prevented from starting up in the oven and stirring up dust particles that settle on the fresh japan. It is important to prevent this as far as possible, as these dust particles raise small lumps on the smooth japan surface, which are pyramidal in form so that they radiate light from all sides, which makes them appear much larger to the eye than they really are. When the pipe coils are arranged in this way, a dry heat is secured which bakes the japan quicker and harder than when moisture is present, as in the case of an open flame or when using steam heat. The atmosphere in the oven is also kept neutral, because there is no open flame to burn up the oxygen and leave an excess of nitrogen. Owing to these facts, less than 2% of the work requires to be done over, while in the case of gas fires or steam-heated japanning ovens, from 10 to 20% of the work has to be re-japanned and re-baked.

Details of Oil Burning Apparatus. Five burners are arranged along each side of the 50-ft. length of oven and each burner shoots the oil flame into a separate coil of 10-in. wrought iron pipe. A sheet metal pipe is used to convey the spent gases to a central stack that goes to the roof at the point where the coil leaves the oven. The fuel oil is vaporized inside the megaphone and combustion first takes place at this point, so that only the clean flame shoots into the pipe coil, as shown. This arrangement allows the operator to see the flame that enters the pipe coil and adjust the burner in such a way that there will be complete combustion of the fuel oil. If there should be an excess of oil, it would drop to the floor at the end of the megaphone. The importance of the megaphone burner should be emphasized in connection with construction of this kind, as without its use, the pipe coils will be destroyed in a few weeks, while with the construction advocated they will last several months. Another point of importance is that the pipe coils should be supported on rollers so that the expansion and contraction will not crack the piping. If any of the small details of this system are neglected, the result will be failure, but when all details are perfect the process works successfully and is by far the cheapest of any in fuel consumption and upkeep of which the writer has knowledge.

A special casting is placed in the outlet end of the pipe coil to reduce the 10-in. diam. to 4 ins., which leaves a large enough opening to carry away all the spent gases and holds the heat inside the pipe coil where it will radiate to the japan baking oven. If this were not done, 40% of the heat generated by the oil flame would pass through the pipe coil and out of the stack. In one case known to the writer, a heavy sheet metal stack 3 ft. in diam. was burned through by these gases some 2 ft. above the roof of the building and 50 ft. away from the heating coils, as measured by the piping through which the burning oil gases travel.

With a 10-in. pipe left open to the draft from a stack, the burning gases travel fairly quickly through vent pipes like that at *C*, and their heat will not be effective until they accumulate in

TABLE XXII. COMPARATIVE COSTS OF GAS AND FUEL OIL IN HEATING JAPANNING OVENS

General Information	Gas fuel — 3 ovens	Fuel oil — 3 compartments	Fuel oil — 2 compartments
Truck and carrier capacity, cu. ft.	105	260	......
Oven or compartment capacities, cu. ft.	630	780	520
Cubic-feet of springs baked per 21-hr. day (24 heats day and night)	15,120	......	......
Cubic feet of springs baked per day (30 heats in 10 hrs.)	......	23,400	15,600
Cubic feet of springs baked per month (25 working days)	378,000	585,000	390,000
Gallons of fuel oil burned per (25 working days)	......	3,325	......
Cost of fuel per month *	$225.00	$182.88	....
Cost of fuel per cubic foot of springs baked *	$0.0006	$0.0003	$0.00028
Cost of fuel per month †	......	$116.38	....
Cost of fuel per cubic foot of springs baked †	......	$0.002	$0.00017
Saving in cost of fuel (spring capacity 378,000 cu. ft. per month)	......	$112.50	....
Saving in cost of fuel (spring capacity 390,000 cu. ft. per month) *	......	......	$124.80
Saving in cost of fuel (spring capacity 585,000 cu. ft. per month)*	......	$175.50	....
Saving in cost of fuel (spring capacity 378,000 cu. ft. per month) †	......	$149.40	....
Saving in cost of fuel (spring capacity 390,000 cu. ft. per month) †	......	......	$167.70
Saving in cost of fuel (spring capacity 585,000 cu. ft. per month) †	......	$234.00	....

* Gas, 70 cts. per thousand feet; fuel oil, 5½ cts. per gal.
† Gas, 70 cts. per thousand feet; fuel oil, 3½ cts. per gal.

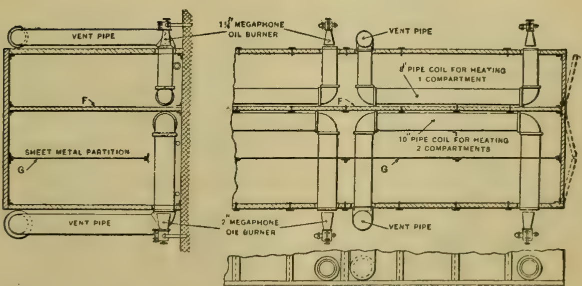


Fig. 6. Sectional view of ovens, showing method of installing pipe coils for fuel oil heating.

the larger stacks outside the building. In an oven arranged like this, with ten burners and pipe coils venting into one central stack, it can be readily seen that there would be an intense heat at the point of concentration unless the flames were held back in the pipe coils until they had burned out. The simplest method of doing this is by means of a casting which reduces the outlet end of the pipe coil, thus obviating the necessity for dampers which burn out too easily.

Fig. 6 shows a floor plan and elevation which indicates the location of these pipe coils and oil burners. It will be seen that a heat insulated partition *F* extends clear to the floor and separates compartments 1 and 2 from compartment 3. This arrangement permits compartment *3* to be fired alone.

INDEX

CODEX PAPERS

Diagrammatic Methods of Computation and Graphic Methods of Presenting Facts have had probably as much influence on the advancement of modern engineering practice as any of the modern developments in the art. A curve is not half so terrifying as a formula to the "practical man," and it is ever so much more convenient to handle for anyone.

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